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An Examination of Interim Emission Control Strategies for Heavy Duty Vehicles (A Regulatory Support Document)

by
The Emission Control Technology Division
Office of Mobile Source Air Pollution Control
United States Environmental Protection Agency

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ABSTRACT

The Emission Control Technology Division of the Office of Mobile Source Air Pollution Control has examined the need for, and possible strategies for, achieving reductions in gaseous and smoke emissions from heavy duty vehicles and their powerplants. The relationship of existing test procedures to urban mass emissions, the technology available to meet reduced emission levels, the cost of various controls and their effectiveness are each examined in arriving at an optimum strategy for near term application to heavy duty vehicles.

1. Introduction

Exhaust emissions from heavy duty vehicles (HDV) were first regulated in California beginning with the 1969 model year. The standards applied only to gasoline engine hydrocarbon (HC) and carbon monoxide (CO) emissions. EPA adopted the California standards and test procedures in 1970 and added a separate smoke procedure and standards for Diesel engines covering all 50 states. In 1972 California lowered the HC and CO standards. In 1973 California revised the gasoline test procedure to a mass measurement basis, added a standard for oxides of nitrogen (NOx), established a Diesel engine procedure, and extended applicability of revised standards to all types of heavy duty engines. In addition, evaporative HC standards were established for gasoline fueled vehicles. EPA adopted the 1973 California package with the 1974 model year except for the evaporative HC regulation. EPA also added a peak smoke level standard to Diesel engines. For model year 1975, California has lowered gaseous emission levels and has proposed very stringent standards for 1977. Except for minor technical amendments to the regulations, EPA has not proposed any further changes through model year 1978. Table 1 summarizes the past and future standards applicable to heavy duty vehicles through 1977.

Table 1

Past and Future Heavy Duty Emission Standards (a)

Pollutant	1969 (c)		1970-1 (c)		1972 (c)		1973		1974 (h)		1975 (h)		1977-8 (h)	
	C	F	C	F	C	F	C (e)	F (c)	C & F (g)		C	F	C	F
Hydrocarbons	275	NR (b)	275	275	180	275	16	275	16		10	16	5 (i)	16
Oxides of Nitrogen	NR	NR	NR	NR	NR	NR		NR						
Carbon Monoxide	1.5	NR	1.5	1.5	1.0	1.5	40	1.5	40		30	40	25	40
Smoke (d) Opacity	NR	NR	40,20,NR		→		→		20,15,50		→		→	
Evaporative Hydrocarbons	NR	NR	NR	NR	NR	NR	2 (f)	NR	2	NR	2	NR	2	NR

(a) C - California. F - Federal
(b) NR - No Requirement
(c) HC = PPM CO = % mole volume
(d) % Opacity: Acceleration, Lug, Peak
(e) California test procedure modified to state standards in terms of gm/BHP-HR. Diesel engine added to requirements.
(f) Evaporative emissions restricted. 2 grams per test - certified by design.
(g) California test procedure adopted. Diesel engine added to 49 states. HC and NOx combined to a single standard.
(h) HC + NOx = GM/BHP-HR, CO = GM/BHP-HR.
(i) Alternative standards of HC = 1.0 GM/BHP-HR, NOx = 7.5 GM/BHP-HR, are provided for the manufacturers option.

The test procedures associated with heavy duty vehicles are engine dynamometer exercises at steady state conditions. Unique procedures are applied to the gasoline and Diesel engines. These exercises are described as "9" and "13 mode" tests respectively. The Diesel smoke test procedure is a unique and separate transient test procedure.

The original heavy duty engine standards represented a very small improvement over uncontrolled levels for HC and CO. The 1974 California and 1975 Federal standards at best represent a 55% reduction for gasoline engines and almost no reduction for Diesel engine gaseous emissions. This contrasts with the 80 + %* reduction in light duty vehicle emissions represented by the 1975 interim standards. In addition, long range agency planning documents (1) have assumed equitable treatment of all categories of mobile sources. Although past assumptions need not restrict future regulatory action, continuation of mobile source control strategies, which are less stringent than LDV strategies, affects the air quality impact basis upon which previous decisions have been made. These factors, coupled with the fact that current and proposed standards for control of other mobile sources are not sufficient to allow achievement of national ambient air quality standards, suggest a need to examine heavy duty vehicle control strategies for the years to come.

The information presented and analyzed in this report is aimed at identification of a cost effective emission control strategy for short term application ot heavy duty vehicles and their power plants. The analysis is based on the assumption that recently proposed revisions to the definition of Light Duty Truck will be adopted such that heavy duty will encompass primarily vehicles over 8500 pounds gross vehicle weight rating (GVWR)(2). Those trucks in the range of 6000 to 8500 pounds GVWR, formerly heavy duty, will become light duty. Thus, in terms of 1973 sales data the heavy duty class would be approximately 40% of its former size (3). On a vehicle miles travelled (VMT) basis the revised light duty truck class and heavy duty class represent 60 and 40% of total truck VMT respectively (4).

The objective of the report is to provide answers to the following broad questions and to adequately address the issues contained therein.

1. What level of control is technologically feasible for heavy duty gasoline and Diesel engines?

2. What costs are associated with the various technology options over the useful life of the vehicles?

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*NOx excepted.

(1) Numbers in parenthesis correspond to references listed on the last page of the report.

3. To what extent are reductions measured by current test procedures real reductions in urban emissions?

4. Should HC and NOx as well as gas and Diesel engine designs be treated on a separate standards basis in the short term?

5. What optimum regulatory approach is appropriate for application to heavy duty vehicles including standards, test procedures and time phasing?

The report presents conclusions and recommendations immediately following the introduction. Following the conclusions, section III of the report examines the current heavy duty vehicle control strategy. Included are detailed discussions of test procedures, their relationship to on the road emissions and needed improvements. The existing standards and the issue of separate versus combined standards are treated.

Section IV explores the availability of technology and the levels of control achievable, and the impact of proposed California standards is described. The fifth section presents cost effectiveness calculations and comparisons to other mobile source strategies.

The need for additional emission control of mobile sources as well as the environmental and economic impact of the several control strategies are found in the Environmental and Inflationary Impact Statement (Ref. #16).

II. Summary of Conclusions and Recommendations

The current Federal Heavy Duty engine dynamometer test procedures (FTP) were carefully examined in terms of their inherent technical weaknesses and resulting ability to estimate actual emissions of in use trucks on an urban road route. The result of this examination was the identification of mathematical relationships for predicting road route emissions from FTP measurements. In general, there was good statistical correlation between the FTP and road route for all constituents except Diesel CO emissions. However, the existing tests were found to be poor "predictors" of CO and NOx emissions in that a given reduction in terms of FTP emissions results in a much smaller reduction in actual road emissions. This is partially explained by the lack of certain characteristic operating modes in the current procedures as well as improper mathematical weighting of the existing modes. Thus, there is clearly a need to develop procedures and operating exercises which correlate one for one with urban emissions. However urban emission reductions, especially hydrocarbons, can, with the current test procedures, be estimated with reasonable confidence as an interim step.

Several procedural and instrumentation improvements were also identified as necessary to make it possible to measure advanced control system engines with reasonable accuracy. A revised sampling and analytical system using chemiluminescence and flame ionization for measurement of total NOx and hydrocarbon has been developed. In addition, the gasoline 9-mode test reference points were redefined in terms of percent load instead of manifold vacuum. Equivalence ratios for adjusting the standards to account for changes in the procedure have been developed from preliminary data. The effect of substituting an FID for NDIR on HC measurement is a multiplicative increase of 1.3 to 1.4. 1.4 was used in determining proposed standards. The effect of substituting chemiluminescence and a convertor for NDIR on NOx is a multiplicative factor of .9 to 1.0. Equivalence was assumed in determining proposed standards.

The issues of having unique standards for gas and Diesel and separation of currently combined HC and NOx constituents were examined. Both types of powerplants potentially provide the same service function and there are no data to quantify any potential difference in stringency between the two test procedures. Therefore, no justification exists for having unique standards.

The agency has determined that oxidant control is best approached through control of hydrocarbons, while ambient NOx levels are the major justification for NOx control. Therefore, there is no long term justification for continued combination of HC and NOx as a single standard. However, tradeoffs have already been made between the two constituents; yet, for the short term, some incentive can be given to control of HC by stating a separate HC standard and continuing with a combined total HC + NOx standard. This approach is recommended for an interim step.

The availability of emission control technology to apply to heavy duty engines, the level of control achievable, and the expected capability of the various manufacturers to apply such techniques to production engines were examined. Very low levels of emissions (90% from a 1972 baseline) were achieved in laboratory experiments using combinations of oxidation and reduction catalysts and EGR on several heavy duty engines. However, reduction catalysts have not been used in production automobiles or trucks. Therefore, of the three, only oxidation catalysts and EGR are considered viable control techniques for an interim strategy.

Manufacturers' data were solicited in a series of individual meetings to determine their positions regarding achievable future standards. Although several have engines capable of meeting the 5 gram HC + NOx and 25 gram CO standards proposed by California for 1977, rather severe fuel penalties for the gasoline engine of at least 7% and 3 to 5% for Diesel as well as restricted availability and substantial first cost increase can be expected. Attention was focused on levels of emissions achievable with no increase in brake specific fuel consumption (BSFC). Levels of control achievable both with and without catalyst technology were initially determined. Subsequently, as a result of certification of engines to 1975 California standards and additional information supplied to the California Air Resources Board in hearings held February 4, 1975, these initial determinations were revised. It has now been determined that levels of 1.5 HC, 25 CO, and 10 HC + NOx (gm/BHPHR) are achievable by both gasoline and Diesel engines with no increase in BSFC by 1978, using "good" non catalyst technology. This includes improved fuel management, air pumps and some utilization of EGR. Diesel engines, many of which already meet the proposed HC and CO standards, are expected to utilize several different approaches including EGR, improved fuel injection and turbochargers to meet the proposed NOx level.

The ability to reach the previously listed gaseous emission standards with no fuel penalty was based on the assumption that no further reductions in smoke levels would be required. However, examination of current (1975) certification performance exposed the fact that nearly all Diesel engine families have demonstrated the ability to meet a peak smoke level of 35% opacity. The standard is 50% opacity. Therefore, in order to prevent manufacturers from actually increasing smoke levels as a tradeoff against reaching the proposed interim gaseous standards, a 35% peak smoke standard is recommended.

Heavy duty gasoline fueled vehicles are not currently covered by any evaporative hydrocarbon standard except in California where they must meet the light duty standard of 2 grams/test. California specifies the federal light duty test procedure, but certifies the system by design evaluation rather than requiring confirmatory testing of completed vehicles. The degree of evaporative control achievable using current automobile test methods was examined using preliminary data from heavy duty trucks. It appears that although some control of evaporative

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losses can be achieved, if EPA were to now adopt California practices for heavy duty vehicles, much more cost effective control would be possible with a properly designed enclosure based test procedure. Therefore, it is recommended that control of heavy duty vehicle evaporative losses be deferred until such a test procedure and appropriate compliance method can be determined.

The cost effectiveness of heavy duty vehicle interim control was calculated and compared to other mobile source control alternatives. An increased first cost of approximately $110 per gasoline fueled vehicle can be associated with the proposed standards. The $120 estimated increase in Diesel engine cost amounts to less than 0.1 cent per mile additional operating expense because of the limited first cost increase. Lack of a fuel penalty for either gasoline or Diesel engines, results in heavy duty interim emission control at least as cost effective as control of LDVs and LDTs to interim levels, and more cost effective than other anticipated mobile source emission control strategies.

For the reasons outlined in this summary and others detailed in the report to follow, it is recommended that the agency adopt an interim control strategy for application to heavy duty vehicles beginning in model year 1979. Standards of 1.5 HC, 25 CO and 10 HC + NOx (gm/BHP-HR) exhaust emissions with 35% peak smoke opacity should be proposed by NPRM as soon as possible.

III. Current Heavy Duty Vehicle Test Procedures and Potential Improvements

This section of the report examines the exiting test procedures, their origins, limitations, and potential improvements. In addition, the current standards and the issues of equivalent gas and Diesel and combinatorial HC and NOx standards are examined.

A. Test Procedures:

1. Current Methods and Their Weaknesses.

Two test procedures currently exist for examination of heavy duty engine gaseous emissions. The "9-mode" and "13-mode" FTP are applied to gasoline fueled and Diesel engines respectively. The test procedures are developments of industry, the 9-mode from MVMA and the 13-mode from EMA, promulgated originally by the State of California and later adopted by EPA without substantial modification. Additionally, a separate smoke test procedure, developed by EPA, which simulates worst case transient manuevers for acceleration and engine lug down is applied to Diesel engines.

The existence of two separate gaseous emissions test procedures is explained by an examination of two factors. First, the gasoline engine was the first of the two types of engines to be controlled in 1969 with Diesel regulation deferred until 1973. Therefore, the gasoline procedure was developed before a need to control Diesels was recognized. Secondly, a Diesel engine cannot be run on the gasoline test procedure because manifold vacuum, the control parameter in the "9-mode" test does not exist on the unthrottled Diesel. In addition, the 2000 rpm constant speed of the "9-mode" test, although characteristic of gasoline engines, is closer to maximum speed for most Diesel engines.

Both gaseous emission test procedures have several inherent characteristics which limit their usefulness for accurate assessment of urban emissions. These include:

a. Steady state operation at each of the mode test points. Actual road usage involves transient operation involving continuously changing acceleration and deceleration rates.

b. Single speed (2000 prm) for the gasoline 9-mode and dual speed (60 and 100% of rated engine RPM) for the Diesel 13-mode.

c. No consideration of cold start influences, as both tests begin from a "warmed up" engine condition.

d. Lack of a wide open throttle (full load) test point for the gasoline 9 mode.

e. Weighting factors for the various modes have questionable relationships to overall urban vehicle use patterns.

f. Specification of gasoline 9 mode reference points in terms of manifold vacuum. The use of manifold vacuum is impossible for supercharged engines and the level of manifold vacuum is affected by application of advanced emission control technology such as EGR.

g. The gas analyses systems use NDIR for all gaseous emissions except Diesel HC measurement. These methods are inaccurate for HC and NOx and are especially unsuitable for application to any lower standards than those that currently exist.

Because of these primary problems, it was necessary to evaluate to what extent the current procedures related to urban mass emissions and also develop technical improvements in the test procedure and instrumentation system.

B. The Relationship of Current Test Procedures to Urban Mass Emissions

The extent to which changes in heavy duty vehicle standards measured with the current test procedures relate to changes in actual urban on-the-road emission was evaluated. Southwest Research Institute (SwRI) has performed warmed-up emissions testing of heavy duty gas and Diesel trucks over the San Antonio Road Route (SARR), an actual urban road network. (5,6) At the present time, EPA is analyzing extensive HDV operational data in New York and Los Angeles with a smaller data base from St. Louis. These data will be used to develop representative HDV chassis driving cycles (speed vs. time) and representative HDV engine driving cycles (RPM and load vs. time). If necessary, distinct representative driving cycles will be determined for buses, 2 axle gas trucks, 3 axle gas trucks, tractor trailer gas trucks, 2 axle Diesel trucks, 3 axle Diesel trucks, and tractor trailer Diesel trucks. These cycles will consider hot/cold weighting factors and will be generated using MonteCarlo techniques from a data base consisting of over 350 truck days of operational data. Until this analysis is complete, sometime in 1976, EPA does not have definitive information on how representative a given driving cycle is. Table 2 compares summary statistics over the SARR with preliminary truck operational data from New York City.

Table 2

Comparison of SARR with Preliminary New York City Truck Data

Percent Time at Idle	Range	Average Speed (mph)	Speed Range (mph)	Percent of time at various speeds (mph)				
				Idle	≤10	10.01-20	20.01-30	30.01-40
SARR[a]	8.7-29.5	19.6	17.2-25.9	19.0	10.0	20.4	31.8	10.3
NYC [b]	12.1-61.4	11.6	3.2-17.3	37.5	20.8	17.2	10.3	6.2

a/ Reference 5
b/ Reference 7

Examination of this table indicates the trucks in New York City tend to have lower average speeds and spend more time at idle than trucks driven over the SARR. One major reason for this is that the SARR represents truck operation over an origin to destination route. NYC data, on the other hand, represent truck operation on a daily basis and as a result, incorporate idle time accumulated between trip deliveries. This factor may partially account for the difference in percent of time spent at idle and average speed although SARR and NYC results do overlap on an individual truck basis. It is thought that a more major reason for the apparent difference can be attributed to the extreme traffic congestion which exists in NYC.

The Vehicle Operations Survey (CAPE-10), conducted under joint sponsorship of EPA and the CRC, supports this hypothesis. (7) The purpose of the VOS study was to define, determine, and typify automobile driving patterns in terms of operating modes. Data were collected in five major metropolitan areas (New York City, Chicago, Cincinnati, Houston, and Los Angeles) and subsequently combined to form an overall composite of urban driving patterns. Of special interest is the fact that automobiles in New York City have lower speeds and spend more time at idle than do automobiles in the other four cities. These results are shown in Table 3.

The LDV results shown in the table would support the hypothesis of lower average speeds and higher percent time spent at idle for trucks operating in New York City when compared to trucks operating in other metropolitan areas.

One last point concerning driving cycles should be mentioned. The average speed for LDVs over the LA-4 is 18.9 mph and, on the urban dynamometer driving schedule (UDDS), is 19.7 mph. The percent time spent at idle is 18.2 percent for both of these cycles. Since SwRI has indicated that the trucks tested tended to keep up with LDV traffic over the SARR, the SARR tends to closely approximate the LA-4 and UDDS. This is further confirmation that the SARR should result in an air quality related emission measurement for trucks.

Table 3

Comparison of LDV Operation Data from 5 Cities

Operation Data	N.Y.C.	Chicago	Cincinnati	Houston	L.A.
Average Speed, Freeway, mph	40.5	46.5	54.6	50.3	48.7
Average Speed, Non-Freeway, mph	17.8	21.3	22.4	23.0	23.2
Average Speed, Overall, mph	21.6	24.5	25.9	27.7	29.3
% Total Time, Idle	17.5	14.1	11.3	11.3	10
% Total Time, Cruise	26.5	30.9	30.7	36.8	34.3
% Total Time, Accel	29.1	28.3	30.9	27.4	29.8
% Total Time, Decel	27.0	26.8	27.0	24.6	25.9

EPA is pursuing the work necessary to develop representative urban truck driving cycles. In addition, work is ongoing to evaluate the sensitivity of truck emissions to average vehicle speed and to various cycles at the same average speed. When this work is completed, a minimum set of air quality related driving cycles will be available. However, after evaluation of the currently available data, the SARR can be judged as an acceptable cycle over which to assess air quality related truck emissions. It is an actual urban cycle and as such, it is superior to any non-transient cycle. The SARR is the only urban road network over which actual mass emissions of trucks have been measured.

SwRI has performed emission testing of the same heavy duty gas and Diesel trucks over the SARR as well as by the appropriate Federal test procedure. For each truck tested, measurements of grams of pollutant/pound of fuel are obtained for both the road test and the engine dynamometer test. Regression analysis was performed in order to relate the emission rate on the dynamometer cycle to the road emission rate. Examination of the data indicated that the relationship was linear over the region where data existed. This assumption was supported by linear correlation coefficients of .8 or higher. A graphical representation of

the regressions is given in Figures 1 and 2 (pages 12 and 13), for gas and Diesel trucks respectively. The solid line on each graph represents the best fit linear regression line. The dotted lines represent the 90% confidence interval around the mean predicted road route emissions for a given FTP emission result. The dashed line presents the case where the FTP emissions equal the road emissions. Thus, the more closely the solid line approximates the dashed line, the better the emissions measured over the FTP represent emissions measured during actual urban road operation. The mean of all observations for each pollutant and powerplant (gas or Diesel) is notated with an x on each of the graphs.

The SwRI samples of gasoline and Diesel trucks were selected to approximate the national distribution of trucks with respect to engines and GVWR. Although it is difficult to accurately stratify such small samples (the gasoline sample consisted of 25 trucks and the Diesel sample consisted of 10 trucks), the SwRI samples have the same average GVWR as the national population: approximately 23,000 pounds GVWR for gasoline trucks and 56,000 pounds GVWR for Diesel trucks. Additional variability could be explained for a given size truck by adding GVWR as an independent variable in the regression equations (thus increasing the correlation and decreasing the width of the confidence interval). However, the emission estimates which represent the national population of trucks can be accurately assessed without incorporating weight as a covariate since the input sample of trucks represents the national distribution.

From an engineering standpoint, an emission rate of zero on the dynamometer should result in an emission rate of zero on the road (unless emissions only result from operation over a mode which is present in just one of the two tests). However, forcing a linear regression through the zero-zero point would distort the prediction in the region of actual data and the region of greatest interest. Therefore, in order to accurately fit the data in the region of low emissions, a higher order curve fit would be required. For the purpose of this analysis, the linear regression not forced through zero was considered appropriate since the data appeared linear for emission rates as low as those being considered for the interim regulations. The resultant linear regressions are given in Table 4.

Table 5 (page 15) displays the expected percent reduction in urban road emissions for proposed percent reductions measured by the Federal test procedures. Table entries are obtained by converting grams/bhp-hr to grams/pound of fuel (by using the brake specific fuel consumption) and using the regression equations from Table 4.

Figure 1

RELATIONSHIPS BETWEEN URBAN AND FTP EMISSIONS FOR GAS TRUCKS

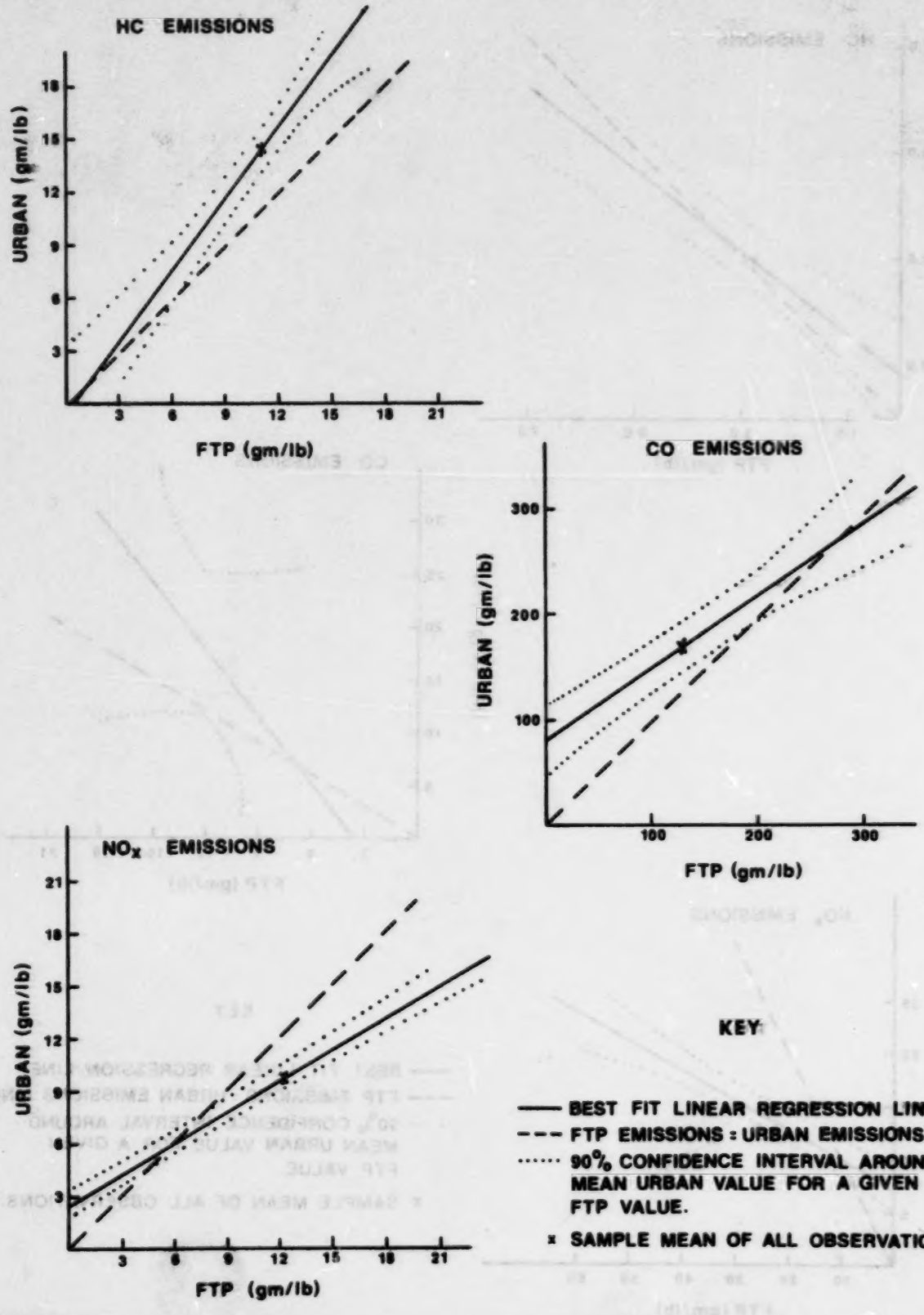


Figure 2

RELATIONSHIPS BETWEEN URBAN AND FTP EMISSIONS FOR DIESEL TRUCKS

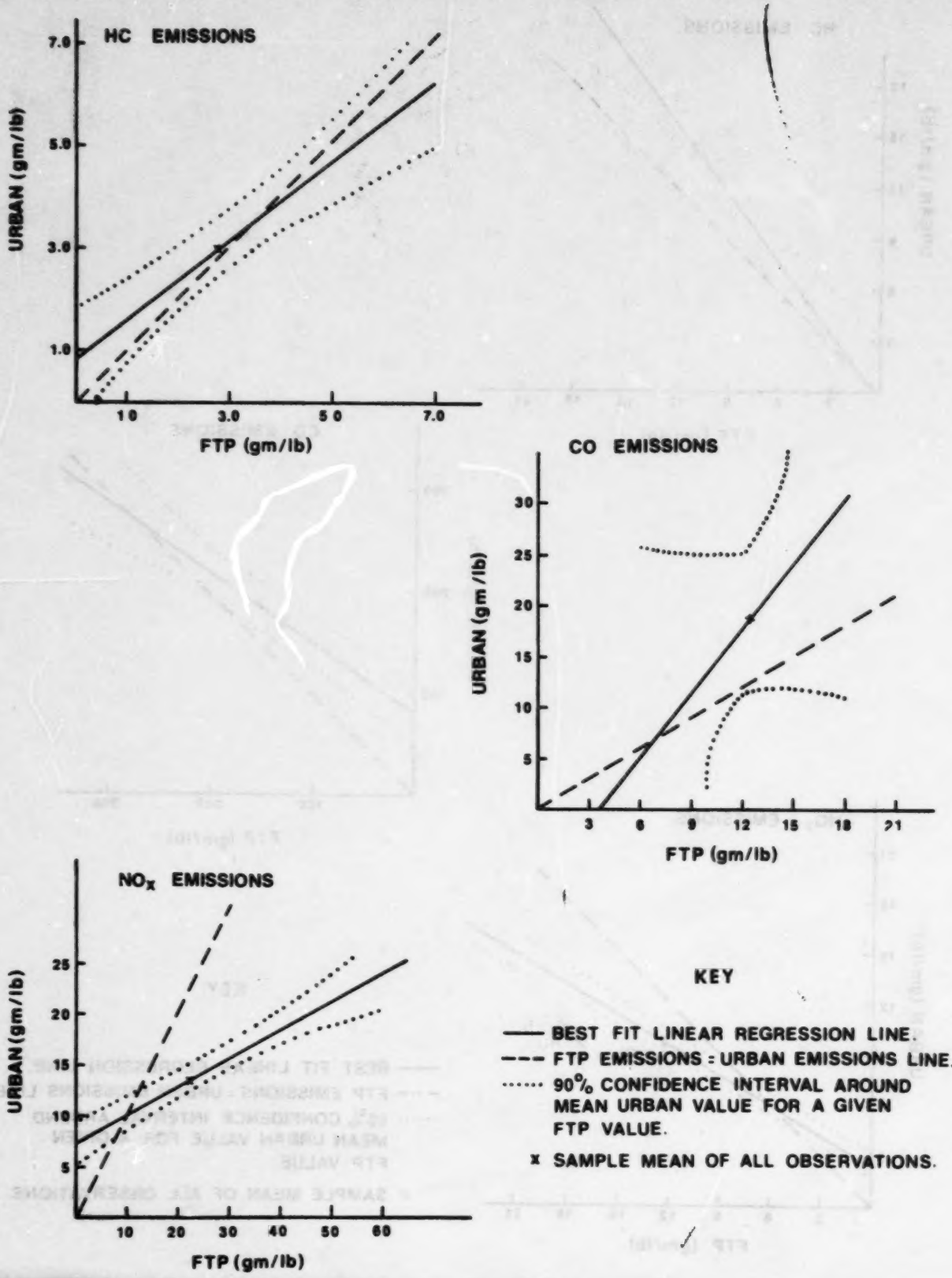


Table 4

Relationship Between SARR Emissions and FTP Emissions(a)

Gas Trucks

$HC_{SARR} = 1.33\ HC_{FTP} - .44, \quad r = .81$

$CO_{SARR} = .689\ CO_{FTP} + 81.1, \quad r = .90$

$NOx_{SARR} = .591\ NOx_{FTP} + 2.57, \quad r = .91$

Diesel Trucks

$HC_{SARR} = .769\ HC_{FTP} + .861, \quad r = .88$

$CO_{SARR} = 2.11\ CO_{FTP} - 7.28, \quad r = .80$

$NOx_{SARR} = .271\ NOx_{FTP} + 7.53, \quad r = .89$

(a) Emissions expressed in grams/pound of fuel.

Examination of Table 5 indicates that for gasoline trucks, decreases in the HC and NOx emissions measured over the FTP accurately reflect the changes in HC and NOx road emissions which would occur if more stringent standards were adopted over current observed levels. For Diesel trucks, the decrease in HC measured over the FTP accurately reflects the decrease in HC road emissions although this cannot be seen from Table 5 since the current range of operation is below the proposed standards. However, decreases in gasoline truck CO emissions and Diesel truck CO and NOx emissions measured by the FTP do not result in equivalent reductions of on the road emissions in the region of current emission performance. Lack of correspondence on the gasoline CO emission and Diesel NOx emission reductions from 1974 levels can be seen in Table 5. The lack of correlation in Diesel CO emissions cannot be seen in Table 5 since Diesel vehicles currently are substantially below the proposed standards. Lack of Diesel CO correlation can be seen in Figure 2.

For gasoline trucks, these conclusions are supported in a study independent of those discussed above, performed by SwRI. (8) The study tested eight gasoline engines over the FTP, the UDDS (with modified accel/decel rates where necessary) and the EPA 23 mode cycles in order to investigate the reductions in exhaust emission levels attainable using various control techniques. Evaluation over the 23 mode cycle and the UDDS assessed the emissions performance of various engines and control approaches during operation of the engine outside the range of the current test procedure. The results are shown in Table 6.

Table 5

Expected Percent Reduction in Urban Road Emissions for Proposed Percent Reductions Measured by the Current FTP

Percent Reduction from 1974 HDV Standards

	Non-Catalyst Technology		Catalyst Technology	
	FTP HDV	SARR	FTP HDV	SARR
Gas				
HC(a)	43	44	71	74
CO	25	8	63	21
NOx(a)	17	13	17	13
HC + NOx	25	27	34	40
Diesel				
HC(b)(c)	--	--	--	--
CO	25	26	63	65
NOx(b)	39	21	39	21
HC + NOx	25	2	34	16

Percent Reduction from Actual 1974 Certification Performance

	Non-Catalyst Technology		Catalyst Technology	
	FTP HDV	SARR	FTP HDV	SARR
Gas				
HC	38	39	69	71
CO(c)	--	--	38	9
NOx	9	8	9	8
HC + NOx	18	21	29	36
Diesel				
HC(c)	--	--	--	--
CO(c)	--	--	--	--
NOx	20	9	20	9
HC + NOx	1	--	13	2

(a) Assume a 1974 standard of HC = 5.22 gms/bhp-hr and NOx = 10.78 gms/bhp-hr based on sales weighted estimate of the 1974 certification HC/NOx split. Standards are adjusted for HC measured by FID.

(b) Assume a 1974 standard of HC = 1.2 gms/bhp-hr and NOx = 14.8 gms/bhp-hr based on sales weighted estimate of the 1974 HC/NOx certification split.

(c) A dash indicates vehicles currently are substantially below 1974 and/or proposed standards - thus comparison of percent reduction meaningless.

Table 6

Percent Reductions in Gasoline Heavy Duty Emissions Measured by the FTP and over the Modified UDDS

	9-Mode FTP	UDDS
HC	85	72
CO	90	51
NOx	54	49

Examination of Table 6 supports the results given in Table 5; that is, the current gasoline FTP overestimates the CO air quality reductions achieved with a change in control technology. This is primarily caused by the lack of a wide open throttle (full load) operating mode which is a characteristic mode for urban driving of heavy duty trucks. Under full load operation, gasoline fueled engines have a fuel enrichment feature designed to provide optimum power. This has the side effect of significantly increasing the CO emission rate.

The fact that changes in NOx emissions measured by the 13 mode FTP do not correspond with equivalent changes measured over the SARR for Diesel engines can also be explained. In general, Diesel trucks emit considerably more oxides of nitrogen under the 13-mode test than when driven over the SARR. This follows when the type of driving represented by the urban traffic route is compared to the intent of the 13-mode test. In the 13-mode test, the idle mode is given a 20 percent weighting factor and each of the remaining speed and load points an equal 8 percent weighting factor. Thus, the 13-mode test gives the same weight to 100 and 75 percent load as it does to zero and 25 percent load. That is, the 13-mode test was developed so as to reflect all types of HD Diesel vehicle operation, both urban and inter-city. The SARR, in contrast, is not a high load factor test since the road course did not stress the vehicle in the way sustained high-speed, high-power inter-city highway driving does. However, it better estimates the emission factors which result when large Diesel trucks operate in and around urban areas.

Test procedure variability and absolute level of emissions explain why CO emissions measured by th 13-mode FTP do not correspond with equivalent changes measured over the SARR for Diesel engines. CO emissions from Diesel are very low and the measurement of these emissions using current instrumentation is extremely variable. Therefore, the actual correlation between FTP and road emissions for Diesel CO is less than any of the other five correlations while the variation in the road route emission levels is considerably greater. These two effects combine to prevent accurate road route predictions from FTP predictions.

In conclusion, the air quality benefits attributed to various control strategies will be computed using the air quality related HDV emissions. Thus, standard changes for gasoline truck CO and Diesel truck CO and NOx will not result in equally large air quality improvements.

C. Gasoline Test Cycle Improvements

The problem of specifying gasoline engine load points in terms of manifold vacuum was evaluated in a separate technical report. (9) The report redefines the "9-mode" test points in terms of percent of maximum torque as opposed to manifold vacuum. Torque points were derived from regression analysis of 19 heavy duty gasoline engines. Table 7 lists the current manifold vacuum levels, derived percent torque levels, and range observed among the 19 engines.

Table 7

Manifold Vacuum and Corresponding Load Levels

Mode[(a)]	Manifold Vacuum	% Observed Torque	Range % Torque 19 Engines
5	19 (in Hg.)	10	5-18
2,4,6,8	16 (in Hg.)	25	22-32
3	10 (in Hg.)	55	51-65
7	3 (in Hg.)	90	78-100

(a) Modes 1 and 9 are idle and closed throttle respectively.

The fact that a substantial variation in torque exists for a given level of manifold vacuum suggests that some engines tested by the modified procedure may have different emission results although on the average, emission levels monitored by the two methods will be the same. Fortunately, gasoline engine emissions are highly sensitive to load variation only near no load and full load operation. Data gathered on eight engines were presented in the report (9) to verify this fact. The expected impact of a change in test points from manifold vacuum to percent load on an individual manufacturer is minor because the no load and near full load emission rates are functions of relatively minor carburetor recalibrations. Near no load, carburetor calibration is affected by "idle" and off idle" fuel rates which are easily adjusted by changing fuel and air bleed openings. Near full load, the adjustment of the "power valve" calibration is usually a change in spring tension on the valve slide.

D. Instrumentation Problems and Improvements

The sampling system and instrumentation associated with current test procedures have several deficiencies. These include measurement of NO only by NDIR when standards are specified for NOx. Additionally, chemical driers are used such that some effect on conversion of NO_2 to NO has been identified. On the gasoline "9-mode" analysis system, HC is measured by NDIR and then adjusted by a constant which was determined to be the relationship between NDIR response and total hydrocarbon measurement using an FID. FID is currently specified for analysis of HC on all other mobile source emission test procedures. The NDIR instrument has severe limitations in accuracy when measuring low concentration levels. Raw concentrations of undiluted exhaust are measured at ambient conditions which results in condensation of water as well as heavy hydrocarbons within sample handling and instrumentation.

An extensive problem analysis and development program aimed at solving the majority of these instrumentation problems was conducted. The effort, recently completed, is documented in two technical reports (10) (11).

The first of these technical reports (10) describes a completely redesigned sample handling and analysis system. The schematic diagram for the system hardware is shown in Figure 3 (page 19). The major changes include: substitution of chemiluminescence analyzers for NDIR to allow measurement of total NOx at low concentration levels; the NDIR hydrocarbon instrument is replaced by FID for gasoline engines to allow accurate "total" hydrocarbon measurement at low concentrations; the need for chemical driers and the problems of hydrocarbon "hang-up" and water condensation have been eliminated by a high bypass ratio heated sample line and ice bath incorporated between the NO_2 to NO thermal convertor and the reaction chamber.

This redesigned system is expected to significantly improve the accuracy of heavy duty engine emission measurement especially at low concentration levels while simultaneously reducing maintenance problems.

The second technical report (11) examines the net impact of the proposed measurement changes on the level of emissions measured and proposes correction factors to be applied to current standards or proposed standards if based on existing sampling methods. Data from several sources including EPA, Southwest Research Institute, TRW Systems, Scott Research and others were analyzed. The relationships are shown in equations (1) and (2) below:

(1) NOx (CHEM) = NO (NDIR) x (.9 to 1.0)
(2) HC (FID) = HC (NDIR) x (1.27 to 1.42) (a)

(a) Includes current test procedure ratio of 1.8.

E. Existing Standards

Standards for the 1975 model year are 16 gm/BHP-HR HC + NOx and 40 gm/BHP-HR CO in 49 states. California standards are 10 gm/BHP-HR HC + NOx and 30 gm/BHP-HR CO using identical test procedures except for the lack of a durability requirement on Diesel engines. Additionally, smoke standards determined by federal procedures for 50 states are 20% accel, 15% lug down, and 50% peak opacity. California also has an evaporative HC standard of 2 gm/test.

The specification of heavy duty gaseous emission standards in units of grams/brake horsepowerhour takes into account the degree of useful work performed by the class of vehicles into which these engines are built. That is, the level of pollutants in terms of mass allowable is directly proportional to the energy output from the engine.

Common numerical standards have been specified for both gas and Diesel engines even though there is a substantial difference in the test procedure which introduces uncertainty about the real degree of equivalency which exists. No data other than those already presented in this section are available to determine equivalency of the two procedures. It is difficult to run gasoline engines by 13 mode procedures or Diesel engines by 9-mode procedure because of the differences in load parameter control and instrumentation. The long term objective is, of course, to have common or at least equitable procedures. However, in the interim it will be necessary to assume equivalence lacking definitive data.

Assuming equivalence in procedure there is no basis for having separate gas and Diesel standards since both engine types provide the same function in commercial service. The two engine types are in competition and the factors which govern the choice of one powerplant over another include:

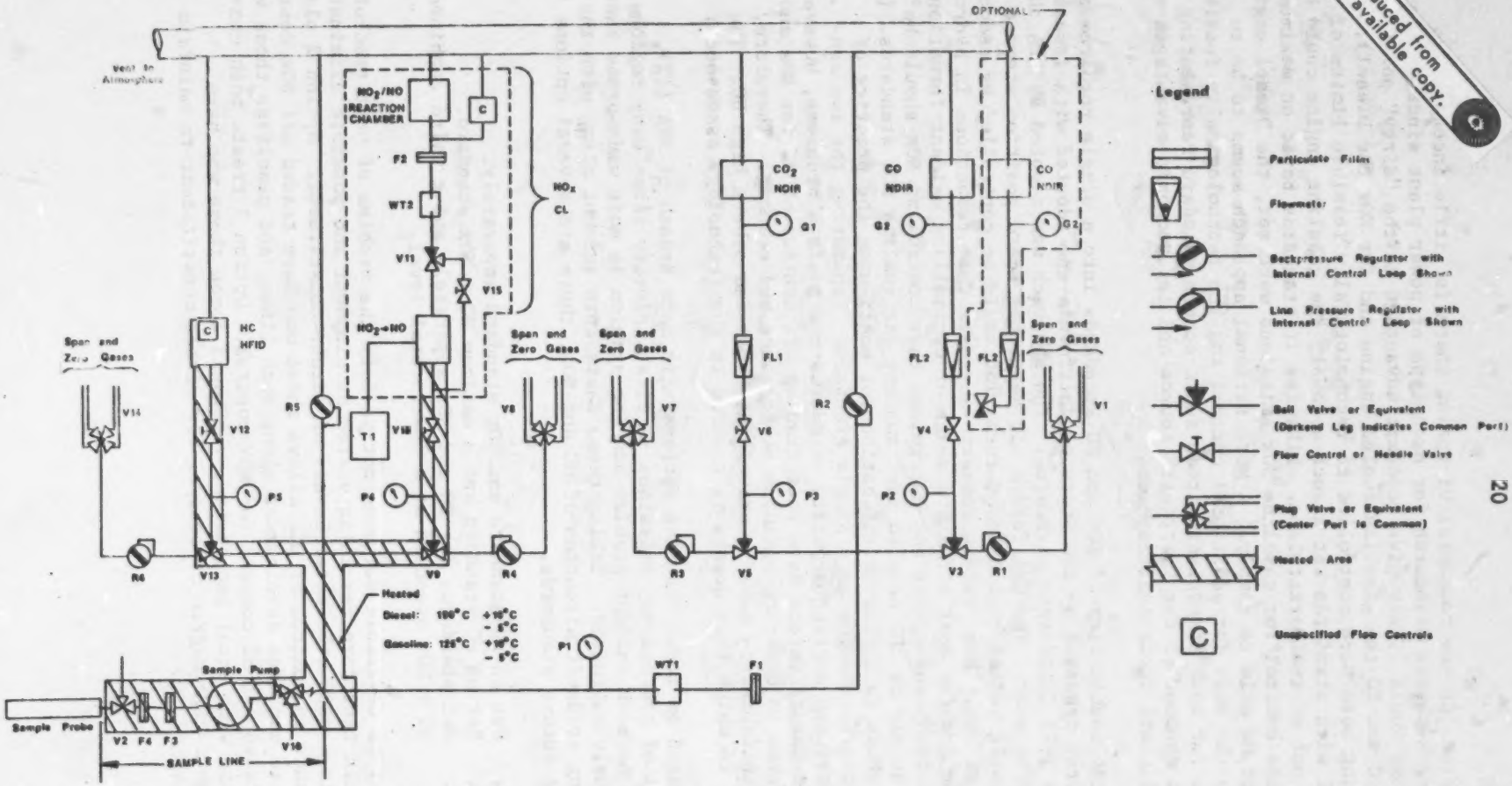
1. First cost - The Diesel engine is approximately 3 times the cost of an equivalent capacity gasoline powerplant.

2. Operating economy - The Diesel engine enjoys approximately 25% better fuel economy when operated in the same size truck.

3. Maintenance - Diesel engines typically operate 200-250,000 miles between major overhauls. This is twice the interval for gasoline engines.

Commercial truck managers carefully evaluate the economic factors before choosing a powerplant. It is extremely doubtful that emission performance plays any role in their decisions.

Figure 3



Legend

- Particulate Filter
- Flowmeter
- Backpressure Regulator with Internal Control Loop Shown
- Line Pressure Regulator with Internal Control Loop Shown
- Ball Valve or Equivalent (Darkend Leg Indicates Common Port)
- Flow Control or Needle Valve
- Plug Valve or Equivalent (Center Port is Common)
- Heated Area
- C — Unspecified Flow Controls

Heavy Duty Exhaust Gas
Sampling and Analytical Train

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From the environmental viewpoint there is little incentive to provide separate standards for each type of power plant since such a strategy would likely give economic advantage to the "dirty" powerplant (for HC and CO the gasoline fueled engine and for NOx the Diesel). Assuming both were controlled to technologically feasible limits of the Diesel with standards set a such a level, the gasoline engine could be ruled out of the marketplace. Likewise if standards based on maximum feasible control for gasoline NOx emissions were set, the Diesel engine may not be able to comply. A more rational approach seems to be to define the need for additional control and the technologically feasible limits for both powerplants, then set a common standard representing strict control of the "dirtiest" source and let economic advantages of each dictate their continued use.

The combination of NOx and HC standards into a single requirement was first proposed by the State of California and adopted with issuance of the 1973 California standards. The approach was adopted by EPA the following year. The California Air Resources Board position stemmed from their belief that oxidant formation could be controlled by reductions in HC or NOx. Most recent research suggests that reductions in hydrocarbons are the most effective means of controlling oxidant formation. In addition, the agency has determined that control of NOx should be based solely on the need to meet ambient air quality NO_2 standards. (12) Thus, there is little justification for continuing the practice of combining HC and NOx as a single standard. Separating the two constituents and setting separate standards now posts a problems, however, in that manufacturers have been trading off control of HC for NOx and vice-versa in order to optimize performance and economy. Therefore, some manufacturers have relatively high NOx and others high HC. The extent to which this occurs is treated in the technology assessment.

Based on input from the National Air Data Branch of EPA (12), control of hydrocarbon emissions is first priority since many regions in the US have an oxidant problem and the problem is more widespread than previously estimated. Taking these facts into account along with the existing tradeoff situation of HC and NOx, there are several options to stating future standards.

1. Set an HC standard and NOx standard separately.
2. Set an HC standard and a maximum HC + NOx standard.
3. Set standards for HC and NOx separately and a third combined HC + NOx standard at a lower total level.

Option 1 is desirable but does not satisfy the problem of past tradeoffs and could therefore result in wasted development and possible elimination of engines with unbalanced levels of either constituent. Option 2 places importance on control of HC, allows those who have traded off NOx control for HC to continue development along such lines, and peanlizes those who have traded off HC control for NOx control. Option 3 treats both constituents with equal importance, yet would force those who have obtained a high degree of control for either constitutent to maintain that control.

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Option 1, totally independent and separate standards, should be the long term goal and will be proposed with adoption of advanced urban operation based test procedures. However, taking into account the facts that control of NOx by existing procedures results in much smaller gains in urban emissions reductions (see Table 5) and recognizing the need to concentrate efforts on HC control which is well predicted by current procedures, option 2 is more appropriate for an interim control strategy. Option 3 would overemphasize control of NOx considering current uncertainties about NOx ambient air quality.

F. Summary & Conclusions

There are three separate test procedures applied to heavy duty engine emissions measurement. These are the "13 mode" and transient smoke test procedures for Diesel engines, and the "9-mode" test procedure for gasoline engines. These procedures have several deficiencies which have been examined in terms of possible limitations on their usefulness for estimating urban emissions, and relationships have been developed to quantify current capabilities. In addition, numerous instrumentation and measurement problems have been addressed through a redesign of the sampling and analytical systems.

Both the 9 and 13 mode tests are good statistical predictors of urban HC and NOx emissions. Also, the 9-mode is a good statistical predictor of urban CO emissions whereas the 13 mode is not. The problem with both procedures is that for CO and NOx there is poor correspondence, i.e., equivalent percent reductions are not attainable. In the short term, with not too stringent standards, significant reductions in absolute levels are possible, but at more stringent standard levels, no additional control may be obtainable.

Test procedure improvements include the substitution of percent load for manifold vacuum as a reference point in the "9-mode" test, substitution of chemiluminescence and FID analyzers for gasoline HC and all NOx measurements, as well as development of a high flow rate heated sampling scheme to eliminate condensation and delay problems. These modifications if adopted will sufficiently improve test procedures to allow reasonable confidence in measuring emission rates.

The issues of separate gas and Diesel standards and separate HC and NOx standards were examined. There is no reasonable basis for having a unique standard for each powerplant design. Neither is there continuing justification for combining HC and NOx as a single standard other than the fact that manufacturers may be able to achieve a higher level of control without loss in marketability of their complete product lines if standards are specified in terms of HC, and HC plus NOx.

IV. Technology Assessment

The capability of heavy duty engine manufacturers to produce engines having lower emission levels was examined as a separate project within LPA. Experimental work was conducted under contract to Southwest Research Institute and the Bureau of Mines on several engines to identify the lowest levels of emissions achievable. In addition, meetings were held with all the major manufacturers to determine the level of technology each has developed, expected fuel penalties associated with various standards, and lead times for various control hardware. Finally, in-house data and manufacturers' data were analyzed to determine current emission performance and fuel consumption rates.

A separate report of the technology assessment panel (K. Hellman and R. Wagner, et. al.) was prepared (13). The information presented herein is limited to the key elements of the panel's efforts. This information included a summary of then current emission performance, analysis of control techniques that could be used to meet various emission levels, fuel penalties and costs. After the preparation of the technology panel report, further information was obtained from manufacturers as a result of hearings held in connection with California's consideration of adopting several alternative heavy duty standards. A summary of these findings is also included. Finally, summary and conclusions of the overall technology report are presented.

A. Current Heavy Duty Emission Performance

The status of current Heavy Duty engines as far as emission performance is concerned, falls into the same two classes as the two engine types, Diesel engines and gasoline engines.

Current Diesel engines exhibit gaseous emissions performance not too much different from uncontrolled Diesel engines. The advances that have been made in Diesel emission control have been primarily in the area of smoke emissions. Substantial reductions in smoke have been made.

Current gasoline emission levels show substantial reductions in HC and CO emissions compared to uncontrolled gasoline engines. NOx levels of current gasoline engines are higher than those of uncontrolled gasoline engines. In general, although reductions have been made in gasoline engine HC and CO emissions, these current values are still not as low as those from current Diesel engines.

The current and uncontrolled levels for Heavy Duty engines as measured by the HDV FTP are shown in Table 8. Also in Table 8 are shown the future California requirements. All percent reductions are based on HDV FTP measurements and are not necessarily percent reductions in urban emissions as discussed in Section III.

B. Control Technology for Heavy Duty Engines

1. HC Control Techniques

Diesel Engines

The HC control techniques available for Diesel engines are primarily those that involve modification of the combustion process. These combustion process modifications are generally obtained by changing the fuel injection timing and/or rate, improving the fuel injector design, changing the air motion in the cylinder during combustion, changing the combustion chamber design, and changing the amount of air available for HC oxidation, for example, by turbocharging. Of these methods, the approach considered most attractive, strictly as an HC control technique, is the approach of improving the fuel injection system. The need for more sophisticated fuel injection systems is apparent to most manufacturers, and some have had active programs to develop improved systems underway for some time. Improved fuel injection systems are an attractive route to improved HC control, since the improvements in the combustion process obtained may well have beneficial effects in other areas; BSFC and smoke, for example.

Another approach toward control of HC emissions from Diesels is the control of crankcase emissions. Currently no requirement exists for Diesel crankcase control. Control of this type of HC emission is well-known, being the positive crankcase ventilation (PCV) valve which has been used on passenger car engines for many years. Although some work will have to be done to adapt the approach to turbocharged engines, control of crankcase emissions from Diesels is feasible. However, there is a need to qualify and quantify Diesel crankcase emissions before adopting a regulation.

Gasoline Engines

The HC control techniques available for gasoline engines parallel those for gasoline LDV. Basically, these techniques include: a) improved air/fuel management, b) changes to the combustion chamber to reduce the surface to volume ratio, c) spark timing retarded away from MBT, d) air injection, e) thermal reactors (both rich and lean), and f) oxidation catalysts.

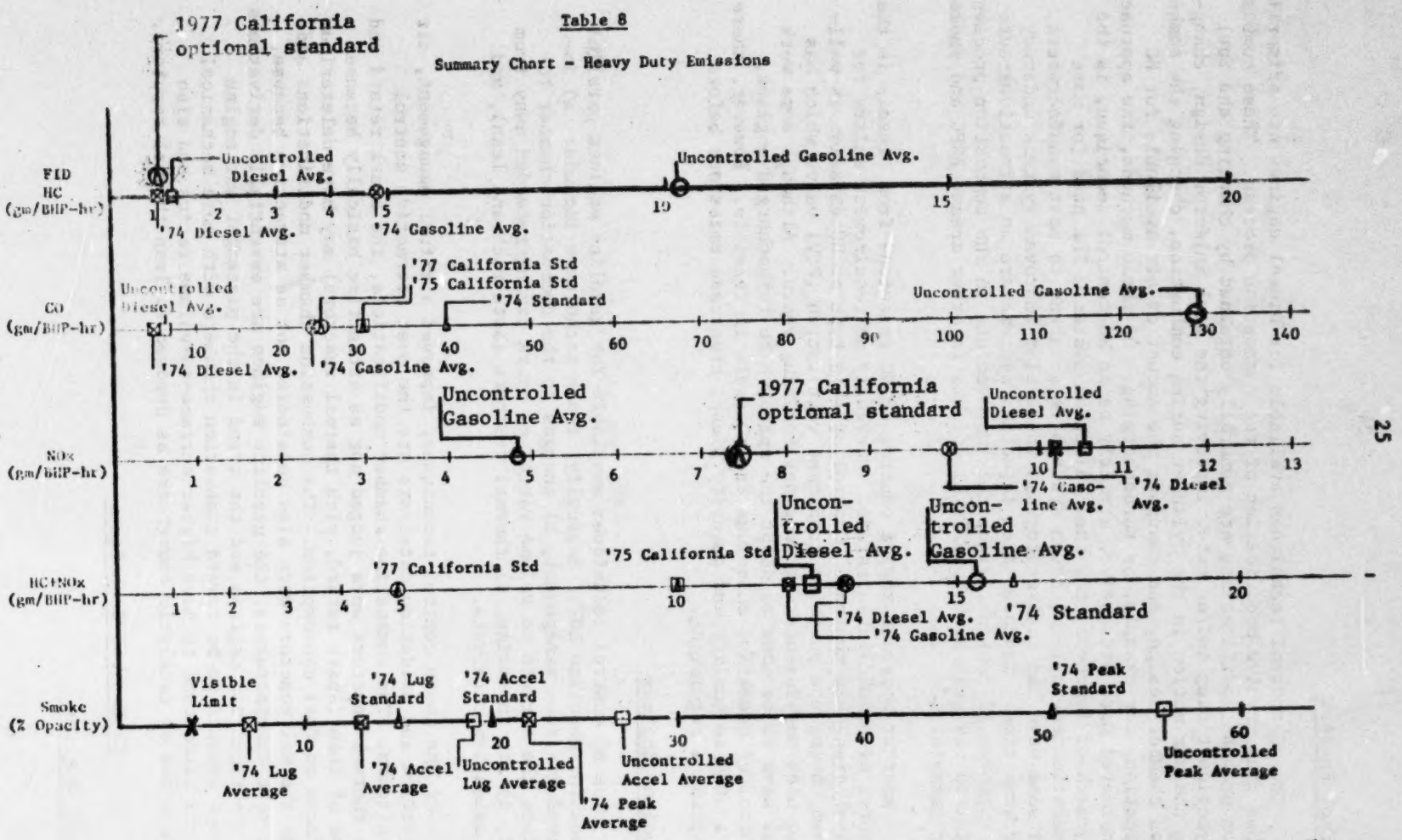
Of the above control techniques, improved air/fuel management, air injection and oxidation catalysts are the most attractive control techniques. The combustion chamber modifications, the spark retard and the thermal reactors were judged not as attractive basically because some of them (spark retard, rich thermal reactors) may have deleterious effects on fuel consumption. The combustion chamber modifications and lean thermal reactors were also considered not as attractive because, for most manufacturers, the gasoline engines are essentially derivations of passenger car engines and the trend in the passenger car engine design appears to be toward combustion chambers with more mechanical octane which tend to have higher surface-to-volume ratios and also toward use of catalytic converters as opposed to lean thermal reactors.

2. CO Control Techniques

Diesel Engines

Table 8

Summary Chart - Heavy Duty Emissions



The low CO emissions from Diesel engines are primarily a function of the lean air/fuel ratio characteristic of Diesel combustion. Techniques that supply more air or better combustion chamber mixing, will lower CO emissions, although there is currently no concerted effort in the Diesel engine field to lower CO emissions, since they are already so low.

Gasoline Engines

Control techniques for CO from gasoline engines are much the same as those for HC emissions, namely, improved air/fuel management (including lean air/fuel ratio operation), air injection, thermal reactors and oxidation catalysts. As is the case with HC control techniques, the most attractive approaches involve improved air/fuel management, air injection, and oxidation catalysts.

The change in gasoline engine test procedure from manifold vacuum to percent power is expected to have greatest impact on CO control. Manufacturers will have basically two options: to set the power enrichment to come in at power levels greater than 90 percent power, if possible, or to design the emission control system to be able to handle the amount of power enrichment that occurs during the test. The first approach, setting the power enrichment in such a way that it is not in operation during the test, may be difficult to do since the percent increase when power enrichment is used is typically greater than 10 percent. Since the first approach involves relatively less effort than the second, the panel considers it likely that some manufacturers may choose to derate their engines in such a manner as to not have the power enrichment occur during the cycle. The possibilities for "false derating", i.e., derating to get by the test with the engine actually producing more power than the manufacturer claims to EPA, is an area that must be considered closely in the certification/enforcement process. A true derating could have beneficial effects on gasoline truck fuel consumption. This is the case if one compares the likely fuel consumption performance of two gasoline engines that produce the same power, one engine (smaller in displacement) operating under power enrichment and the other (larger engine) operating without power enrichment.

3. NOx Control Techniques

Diesel Engines

The techniques available for the control of NOx from Diesel engines are injection timing changes, injection system improvements, altering of the combustion process by combustion chamber design, and addition of a diluent to the air/fuel mixture.

Examples of modifications to the combustion chamber are the changing of the air motion ("swirl" and "squish") during combustion and changing the physical characteristics of the chamber from the common open chamber, direct injection type to one that is more complicated in shape, such as a divided chamber ("swirl camber" or "prechamber), a combination of the two ("poker head"), or a modified bowl type ("squish lip").

Two main diluents have been studied for use in Diesel engines. These are water injection and EGR.

The use of improved injection systems and EGR are believed to be the approaches that will yield the best results in the short term. The use of water injection is not considered to be practical. Changes to different combustion chamber configurations on a widespread basis were not considered to be achievable in the short term because of lead time and industry attitudes toward combustion chambers. It appears that each manufacturer, in general, has his own preferred type of combustion chamber design, which he is somewhat reluctant to change. This attitude coupled with the common wisdom that the combustion chambers with low NOx capability (for example, the prechamber) have higher fuel consumption, has also buttressed the reluctance to change. Even some manufacturers who currently make indirect injection engines are considering changing to direct injection engines in the hopes of improved fuel consumption. However, the common wisdom concerning the direct versus indirect injection engines may not be correct, since the comparisons are rarely made at the same NOx emission level, possibly leading to mistaken approaches by some manufacturers.

The Diesel industry also seems somewhat reluctant to use the EGR approach. Most of the arguments against EGR are not technically valid, but are reflections of uncertainty based on the inexperience of the industry with actual field experience on EGR-equipped trucks. The major technical problem with EGR on Diesels is the proper management and control of the amount of EGR, because a poorly designed system may result in excessive smoke emissions.

Gasoline Engines

Although EGR is also applicable to gasoline engines and is an effective control technique, other methods are applicable to gasoline engines for NOx control. Spark retard is an effective technique, but massive retard was ruled out as a primary NOx control technique due to its effect on fuel consumption. Besides EGR and spark retard, the use of NOx catalysts is possible on gasoline engines. Recent developments in the area of metallic NOx catalysts show much promise for application in the automotive area and this technology is transferable to the Heavy Duty gasoline engine application. However, because of the time frame of the LDV statutory NOx standards that will require use of NOx catalysts (1978), it is likely that use of NOx catalysts on Heavy Duty gasoline engines will lag this 1978 date by enough to put it out of the time frame of this study. Therefore the use of an EGR system of the "super" proportional type was considered to be the most attractive NOx control technique for gasoline engines.

4. Smoke Control Techniques

For Diesel engines the smoke control techniques involve approaches that reduce smoke under two general operating conditions, steady state modes and transient modes. The control of steady state smoke is achieved by reducing or eliminating any pockets of unburned fuel in the cylinder near the end of the combustion process, by changing the fuel injection system, and by improving air/fuel mixing. Turbocharging can help smoke control in steady state conditions because more air is provided to promote complete combustion. Additionally turbocharged engines can be calibrated under steady state conditions to be leaner overall than naturally aspirated engines, yet deliver more power since they are boosted. Transient smoke is controlled by limiting the fuel available during a transient, for example during vehicle acceleration. Without control over the fuel, initially there would be too much fuel and excessive smoke would result. This problem is even more severe with turbocharged engines since the maximum fuel rate is based on the amount of air provided by the turbocharger and at low speed the turbocharger cannot provide all the air that it can when it is up to speed. According to the industry, the technique of limiting the fuel on initial acceleration may have two drawbacks in field use. First, without changing the transmission, a vehicle may not be able to climb out of the sub-surface loading ramps common in many areas. Secondly, drastic limitations on the initial fuel rate may encourage tampering in the field if the drivers feel that their vehicles are significantly down on acceleration power compared to vehicles without the tight controls.

Because there was no firm evidence available to indicate that current 1974 levels of Diesel smoke are objectionable, no further reductions in Diesel smoke were considered. However, the lowering of the standards to current levels of control to prevent manufacturers from increasing smoke emissions through trade-offs is proposed.

5. Emissions and Noise

Much has been said about the "tradeoff" between emission control and noise control, usually via the "increased retard, more cooling, higher fan speed, more noise" argument. There is not necessarily any tradeoff between emissions and noise control for heavy duty vehicles. The noise aspects of any vehicle/engine package will have to be optimized in the future, along with the emissions, and control techniques for noise will have to be implemented. It is possible that the noise control system may be different for engines meeting different emission levels, but this does not mean that there is some tradeoff and one has to give up emission control to get noise control or vice versa. It just means that the overall engine/vehicle system to control both noise and emissions may be different from those designed to control just noise or just emissions. The more frank members of the Diesel industry have indicated as much.

C. Industry Capability at Various Emission Levels

The report team began this study, not by considering specific emission levels per se', but by considering the answers to the following questions:

1. What emission standards will result in the least penalty in BSFC?

2. What emission standards represent the maximum control of HC emissions feasible in the timeframe considered?

3. What is the current industry-wide capability to meet the 1977 California Heavy Duty standards?

4. What emission standards will be achievable by gasoline engines using oxidation catalysts?

1. Techniques for Minimum Fuel Economy Loss

As discussed earlier, techniques applicable to the control of HC and NOx emissions can have the most important influence on BSFC, for a given engine system. At levels of HC and NOx emissions below the current requirements, the fuel consumption change depends to a great extent on what control systems are used to meet the lower levels. The use of injection or spark retard will involve fuel consumption penalties over current BSFC values, for both Diesel and gasoline engines. However, the use of more sophisticated technology than just simple retard can reduce or eliminate these potential losses. Since most of the data and development effort have been expanded toward control of NOx emissions, NOx level was used as the indicator for determining the BSFC impact. The report team concludes that a NOx level of 9 gm/BHP-HR can be met with no significant increase in BSFC. This NOx level will probably require

development of more sophisticated technology than exists on current heavy duty engines. Although there is enough time for the development of this improved technology, manufacturers can also meet our 9 gram/BHP-HR level by recalibrating current engines, if their development programs are not successful, and/or they will accept the fuel consumption penalties of approximately 4 percent that may result if no further development work is done.

The fuel consumption impact of any degree of emission control is a subject of much interest. The industry estimates of these potential losses varies widely as shown in Figure 4 (page 31). The estimates of Caterpillar, Cummins, and General Motors reflect recent development efforts whereas those of Chrysler, Ford, and International Harvestor represent much older development work presented to the CARB in 1973. The gross overestimations of fuel penalty by Chrysler, Ford, and IH as compared to the others clearly represent a lack of development effort by these manufacturers in the opinion of the report team. Furthermore, the report team concludes that the large fuel consumption "penalties" quoted by some manufacturers are more the result of questionable data chosen to try to influence CARB's decision on their standards than they are estimates representative of good faith efforts to achieve the emission levels required with minimum or no BSFC penalty.

2. Maximum Control of HC Emissions

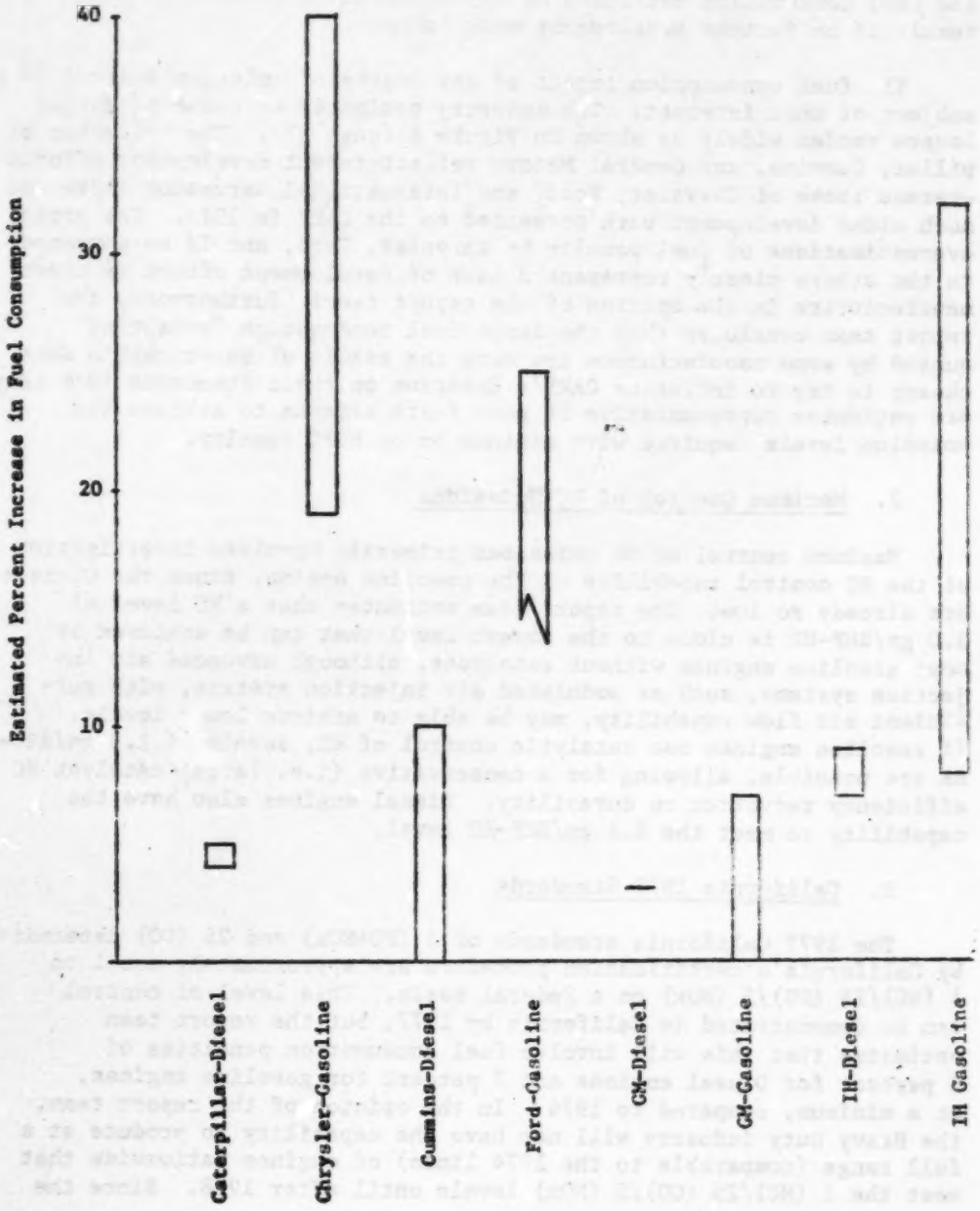
Maximum control of HC emissions primarily involves investigation of the HC control capability of the gasoline engine, since the Diesels are already so low. The report team estimates that a HC level of 3.0 gm/BHP-HR is close to the lowest level that can be achieved by most gasoline engines without catalysts, although advanced air injection systems, such as modulated air injection systems, with sufficient air flow capability, may be able to achieve lower levels. If gasoline engines use catalytic control of HC, levels of 1.5 gm/BHP-HR are possible, allowing for a conservative (i.e. large) catalyst HC efficiency reduction on durability. Diesel engines also have the capability to meet the 1.5 gm/BHP-HR level.

3. California 1977 Standards

The 1977 California standards of 5 (HC+NOx) and 25 (CO) determined by California's certification procedure are approximately equal to 1 (HC)/25 (CO)/5 (NOx) on a Federal basis. This level of control can be demonstrated in California by 1977, but the report team estimates that this will involve fuel consumption penalties of 3 percent for Diesel engines and 7 percent for gasoline engines, at a minimum, compared to 1974. In the opinion of the report team, the Heavy Duty industry will not have the capability to produce at a full range (comparable to the 1974 lines) of engines nationwide that meet the 1 (HC)/25 (CO)/5 (NOx) levels until after 1978. Since the

Figure 4

Fuel Consumption Penalties Estimated by Manufacturers at California 5(HC+NOx)/25 (CO) Standard



time frame considered in this report does not include the post-1978 time frame, meeting the "California" levels of 1 (HC)/25 (CO)/5 (NOx) was not considered feasible, because in this time frame (1978) market demand may not be met. Consideration of emission levels like the 1 (HC)/25 (CO)/5 (NOx) should be re-examined by EPA when the new heavy duty test procedures, now under development, are promulgated. This additional lead time will also give the manufacturers time to optimize and improve their systems, and coupled with the practical experience from field use in California, systems superior to those now planned for California in 1977 could be available on a national basis in the post-1978 time frame, if air quality considerations require their use.

4. Gasoline Engines with Oxidation Catalysts

As the requirements for HC and CO emissions are reduced, the use of oxidation catalysts for Heavy Duty gasoline engines becomes more necessary. For most gasoline engines it has been estimated that HC levels below the 2 to 3 level will require the use of catalysts. CO levels below the 18 to 20 range will also be met most easily by use of catalysts.

D. Development Required to Meet Future Standards

Meeting the standards of 3.0 (HC)/30 (CO)/9.0 (NOx) or 1.5 (HC)/15 (CO)/9.0 (NOx) considered in this report will require development work to avoid the occurance of fuel consumption penalties. Generally speaking, these development programs are underway now, but they must be focused toward these potential standards.

The programs underway to meet the 1977 California standards for Heavy Duty engines will provide the basis for most of the work necessary to meet the standards discussed in this report.

Listed in Table 9 (page 33) are estimates of where the development effort could be concentrated to effectively meet the standards.

E. Control Technology - Summary

Listed in table 10 are estimates of the ranges in gaseous emissions over which different types of control techniques could be used. The applicable range is shown for each control technique. Some control techniques overlap others since each type of technical approach has somewhat different effects on different engines. The values for the 1974 certification results are indicated by the square-ended bars and the estimates for various control techniques are shown with slant-ended bars. Although the 1974 certification results are not adjusted for test procedure differences, other estimates are.

Table 9

Development Effort to Meet
Possible Future H-D Emission Standards

Pollutant	Engine Type: Gasoline H-D Engine	Engine Type: Diesel H-D Engine
HC	Expanded work in the area of air/fuel management, air injection systems. Serious development work required on oxidation catalysts for the 1.5 HC level. Work on developing positive fuel shut off during decelerations should be expanded.	Expanded effort in the area of improved fuel injection systems.
CO	Expanded work in the area of power enrichment versus engine size tradeoffs. More work on air/fuel management and air injection. Serious development work required on oxidation catalysts for the 15 CO level.	Only work needed is monitoring of levels to ensure that CO problems do not occur.
NOX	More development work needed on optimizing EGR rate and control and engine calibrations with EGR. Close monitoring of NOx catalyst development in LDV area.	Serious effort on EGR systems and EGR control and engine optimization with EGR required. More work required on direct injection versus indirect injection engines as a function of NOx level.
Smoke		Development effort required to produce advanced turbochargers that are more controllable. Evaluations of superchargers with superior transient response should be expanded.

Table 10A

Summary Chart Heavy Duty HC Control Technology
Ranges for Various Control Techniques

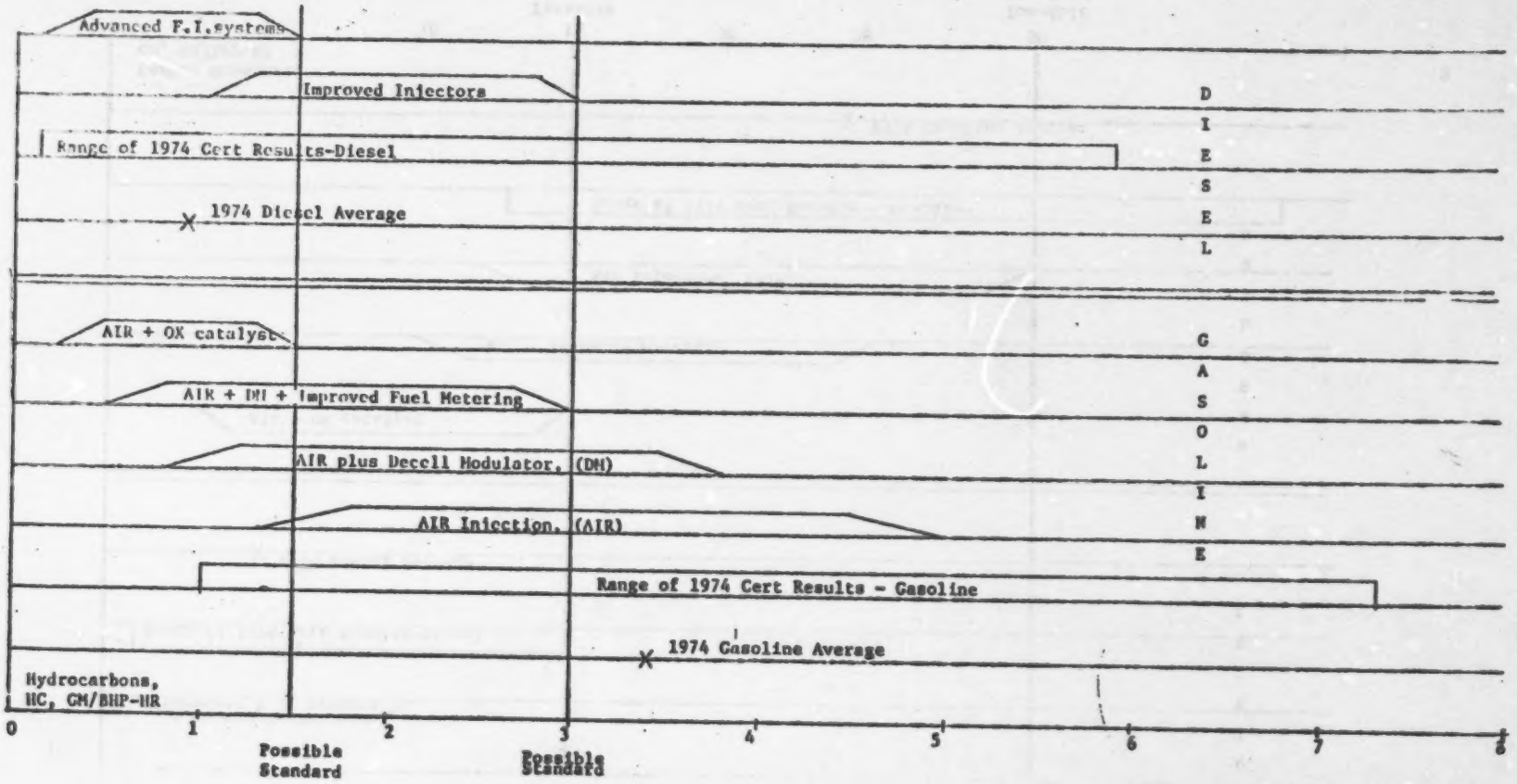


Table 108

Summary Chart-Heavy Duty CO Control Technology
Ranges for Various Control Techniques

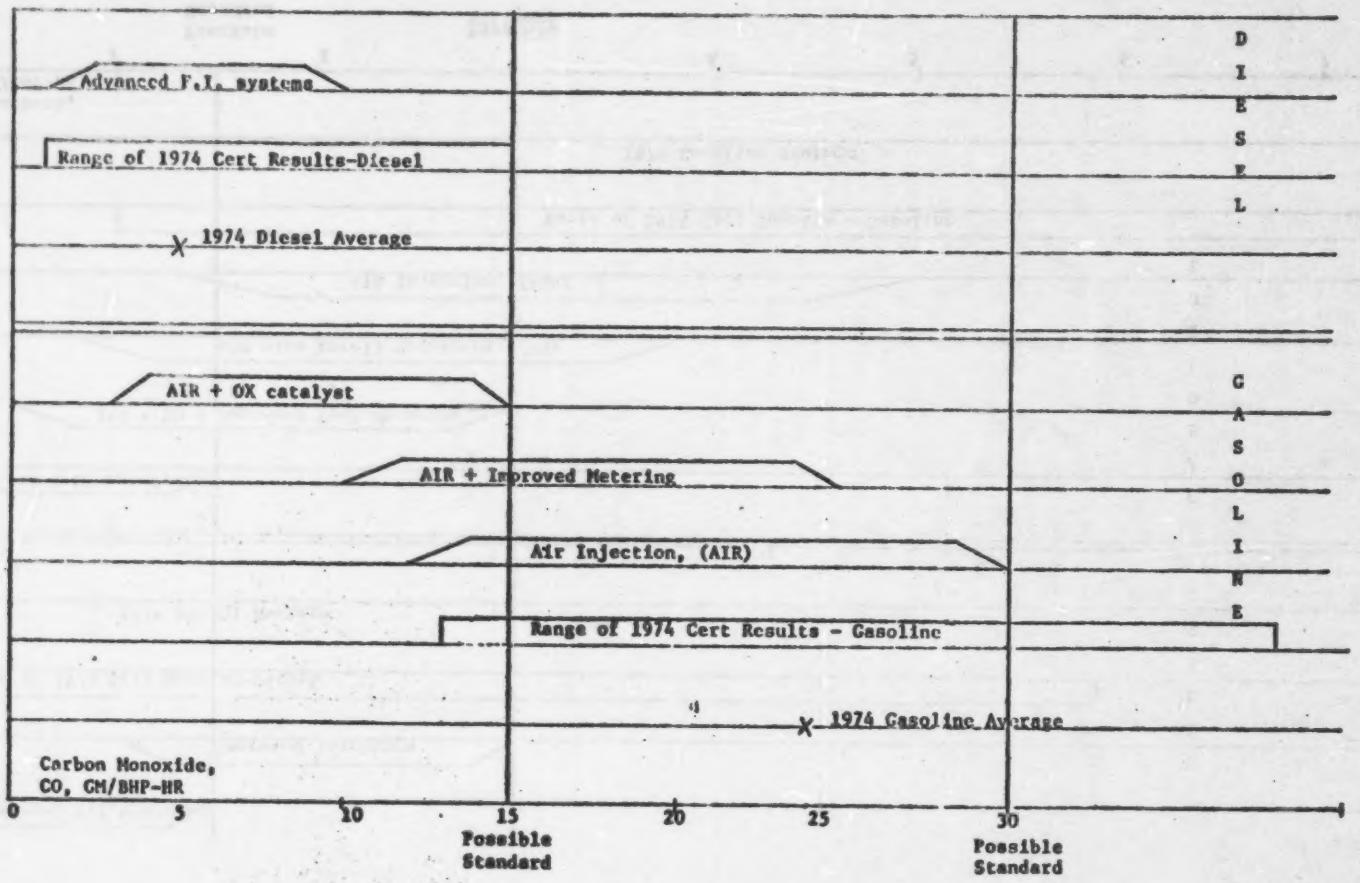
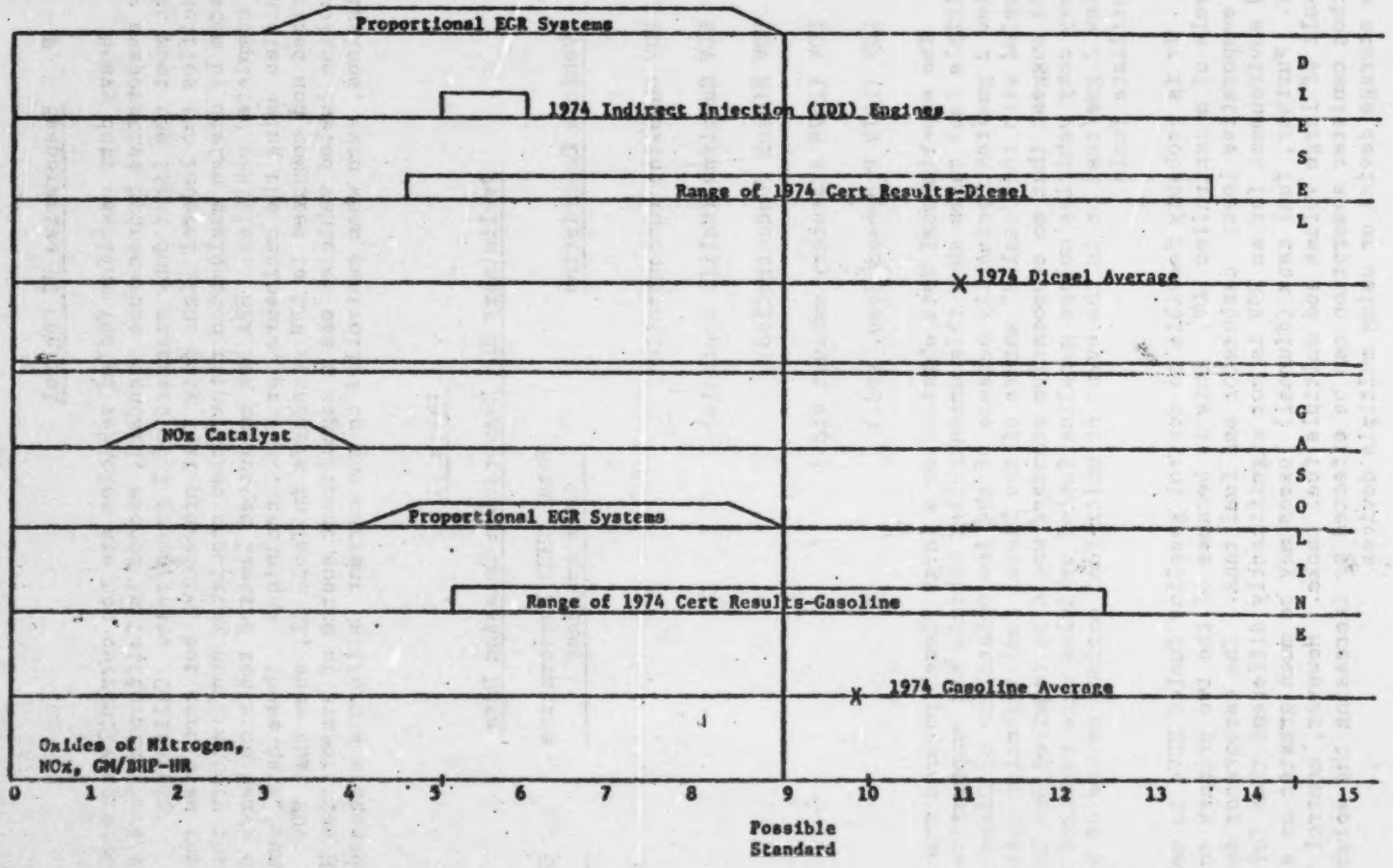


Table 10C

Summary Chart-Heavy Duty NOx Control Technology
Ranges for Various Control Techniques



F. Evaporative HC Control

Heavy duty gasoline fueled vehicles are not currently covered by any evaporative hydrocarbon standard, except in California where they must meet the light duty standard of 2 grams/test. California specifies the Federal light duty test procedure, but certifies the system by design evaluation rather than requiring confirmatory testing of completed vehicles. EPA has conducted limited tests on heavy duty vehicles using the enclosure, or SHED, technique. These data, summarized and compared to LDV standards in Table 11, show that HDV gasoline fueled vehicles are a significant source of evaporative HC emissions, even when controlled to the current California standard.

Table 11

Preliminary HDV Evaporative Emission Data

Vehicle Description	Total SHED Evaporative Loss gms/test	Equivalent HC gms/mi.
1. HDV Gasoline (uncontrolled)	30	2.8
2. HDV Gasoline (Calif. controls)	18	1.5
3. HDV Diesel (uncontrolled)	2	0.1
4. LDV (1978 statutory exhaust std.)	-	0.41
5. LDV (1979 Proposed Evap. std.)	2	0.2

The experimental data obtained on a large Diesel powered tractor with multiple fuel tanks show this uncontrolled vehicle had evaporative losses below 2 gms/test primarily because of the low volatility of Diesel fuel coupled with the "sealed" nature of the Diesel fuel injection system. The data suggest that no evaporative standard would be required for Diesel heavy duty vehicles unless gasoline fueled vehicles were required to go below 2 gms/test or in the event of multi-fuel engines or use of broad distillate fuels.

It is probably feasible to control gasoline fueled HDVs to near the levels of a controlled LDV. This is because of the two primary sources of evaporative loss: carburetor and fuel tank. The carburetor design and environment for an HDV is not significantly different than for an LDV. Further, fuel tank (diurnal) losses may be much greater as a result of large volume and multiple fuel tanks. However, control by carbon canister absorption can be effected by increasing the volume of the storage device or using multiple devices.

The specific hardware employed in such a low emission evaporative control system includes a carbon vapor storage canister, fuel tank vapor

liquid separator, modified carburetor with trapped venting, and miscellaneous hoses and tubing to connect the several components. The cost of such a control system applied to light duty vehicles is approximately $15 per car. For heavy duty vehicles, EPA estimates the per vehicle cost of an effective control system capable of meeting the 2 gm/test standard at $25. This higher amount accounts for the larger canister and additional plumbing of multiple fuel tanks when applied.

The tradeoffs associated with evaporative control includes (in addition to the higher first cost), a slight weight penalty estimated at 10 lbs., and possible increases in exhaust hydrocarbon and carbon monoxide emissions if the storage media is purged rapidly and in a mode of relatively poor combustion efficiency. This latter problem can be minimized through experimental development.

There is no fuel penalty associated with evaporative control, and, in fact, theoretically, there is a slight savings since the fuel previously lost is available for combustion. Such a benefit, if attainable, has not been quantified.

A significant reduction in heavy duty evaporative emissions is expected to be possible with adoption of the current California heavy duty evaporative standard. The magnitude of such a reduction, 1.3 gms/mile, is small in comparison to the reduction in average HC urban emissions resulting from the proposed gaseous emission standard (7.9 gms/mile). At an estimated cost of $25 per vehicle, such control would still be cost effective, but not as cost effective as the control of gaseous emissions to proposed levels (Ref. Table 15).

The primary reason for the limitation in ability to obtain greater reductions in evaporative emissions is the lack of a comprehensive test procedure. The adoption of an enclosure (SHED) procedure is expected to alleviate this constraint, but requires much development before it can be applied to heavy duty. An equally important problem is the method of insuring compliance with evaporative standards because testing requires a total vehicle. EPA currently certifies engines only for heavy duty and would have to begin dealing with total vehicle manufacturers in any compliance program. California has sidestepped this problem by not requiring a demonstration of compliance. Engineering judgment is substituted. The inability to insure compliance by certification testing of all possible vehicle configurations could further erode the estimates of potential emissions reductions obtainable if EPA were to merely adopt the California program.

G. Additional Technology Assessment Information

Several months after the technology assessment panel completed their report, which is summarized in sections A through E, California held hearings to consider the impact of imposing several alternative standards more stringent than their current standards of HC + NOx = 10 gms/BHP-HR, CO = 30 gms/BHP-HR. Specifically, California proposed the following options for 1977:

	HC	HC + NOx	NOx	CO	(gms/BHP-HR)
(1)	--	5	--	25	
(2)	1.5	7.5	--	25	
(3)	1.5	10.0	--	25	
(4)	1.0	--	7.5	25	

An "either or" standard consisting of options (1) and (4) was subsequently adopted. However, in the course of deliberations, manufacturers presented written statements on their ability to comply and the technology and fuel consumption impacts of option (3) which is within the range of standards previously considered by the EPA panel (Ref. 13). The significant findings from these submissions related to the development and demonstrated performance of gasoline engines. All manufacturers stated that they could meet the levels of option (3) using current California systems or minor recalibrations of same. The systems in use are primarily engine modifications (fuel management), AIR, and some EGR. No changes in fuel consumption from current California levels were forecast. GM certification data for 1975 show all California engines currently meet the option (3) levels with slightly improved BSFC over corresponding 49 state engines certified to higher emission levels. Very little (one engine family), if any, catalyst usage by gasoline engine manufacturers was forecast.

Diesel manufacturers could all meet the option (3) levels with little change from currently certified California configurations. However, Caterpillar said they could not meet the 1.5 HC level with one high volume engine family, a direct injection mid-range engine used in intermediate sized vehicles. Cummins forecast a 5% fuel efficiency improvement while other manufacturers cited no change from '75 California levels.

In summary, the development work forecast by the technology panel has been continuing such that the breakpoint for non-catalyst technology capability with no fuel penalty appears to have already moved to levels of HC = 1.5, CO = 25, HC + NOx = 10 gms/BHP-HR. The use of "good" technology as demonstrated by GM and Cummins and available to all, is expected to make such levels achievable in 1979 by all manufacturers over a full product range even after accounting for the change in HC measurement procedure.

H. Standards and Recommendations

Based on analysis of data currently available, it appears that heavy duty engines can meet emission standards more stringent than the current Federal requirements. These standards could be applicable for model year 1979. If not, the lead time necessary to develop and tool up will require approximately two years from the time a NPRM is issued.

For HC and CO emissions, the emissions capability of gasoline engines generally is not as good as Diesel engines. Introduction

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of catalytic control of HC and CO for gasoline engines would bring their emission level capability close to that of Diesel engines. The NOx emissions from current Diesel engines, are approximately 10 percent higher than gasoline engines.

Several sets of Heavy Duty emission standards are possible in the near term. The range encompassed is as follows: $1.5 \leq HC \leq 3.0$, $15 \leq CO \leq 30$, NOx = 9 gms/BHP-HR. Selecting different standards within these ranges primarily impacts the technology expected to be utilized which further impacts the complexity, cost and fuel efficiency of the engines. The standards, their relationship to current standards, and uncontrolled emissions are shown in Table 12.

Table 12
Possible Future H-D Emission Standards (gms/BHP-hr)

	Diesel							Gasoline			
	HC	CO	NOx	HC+NOx	Smoke (A)	Smoke (L)	Smoke (P)	HC	CO	NOx	HC+NOx
Uncontrolled Levels	1.2	6.4	10.5	11.7	27	19	56	10.2	130	4.9	15.1
Current 1974 Standard	-	40	-	16	20	15	50	-	40	-	16*
% Reduction from Uncontrolled	-	none	-	none	26%	21%	11%	-	70%	-	None
1974 Average Performance	.9	5	11.2	12	13	7	22	3.4*	24	9.9	13*
% Reduction from Uncontrolled	25%	21%	[-6%]	[-3%]	52%	63%	61%	(53%)	81%	[-102%]	(3%)
Possible Future Standard (No catalyst for gasoline engine)	3.0	30	9	-	20	15	50	3.0	30	9	-
% Reduction from Uncontrolled	none	none	14%	-	20%	21%	11%	71%	77%	None	-
% Reduction from 1974 Standard	-	25%	-	-	0%	0%	0%	-	25%	-	-
Possible Future Standard (No catalyst for gasoline engine)	1.5	25	-	10	20	15	35	1.5	25	-	10
% Reduction from Uncontrolled	None	none	-	15%	20%	21%	38%	85%	81%	-	34%
% Reduction from 1974 Standard	-	38%	-	38%	0%	0%	30%	-	38%	-	38%
Possible Future Standard (catalyst on gasoline engine)	1.5	15	9	-	20	15	35	1.5	15	9	-
% Reduction from Uncontrolled	None	none	14%	-	26%	21%	38%	85%	88%	None	-
% Reduction from 1974 Standard	-	63%	-	-	0%	0%	30%	-	63%	-	-

* NDIR HC
Numbers in ( ) are corrected for instrument difference in sensitivity between FID and NDIR.
Numbers in [ ] are increases in emission rates.

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No fuel consumption penalty for either set of possible standards is expected if the manufacturers optimize for both emissions and fuel consumption, which is possible using technology which can be available for all engines by 1979. In fact, based on recent light duty vehicle performance, it is expected that a recovery of any existing fuel penalty will be possible if catalyst technology is applied to gasoline engines.

The first costs associated with the two possible sets of standards depend on the technology used to meet the standards. Some of the technical approaches that will be used to meet the standards will involve costs that are not directly attributable to just the standards. With fuel consumption a major concern, the engine system choice will require a more sophisticated system than one that would just meet the emission standards with no regard for fuel consumption. Therefore, the cost attributable to just meeting the standards are difficult to quantify. However, the cost for the entire system, optimized for both fuel economy and emissions, can be estimated. These estimates are shown below.

Table 13

Cost Per Engine Over 1974 Base to Meet Possible Emission Standards

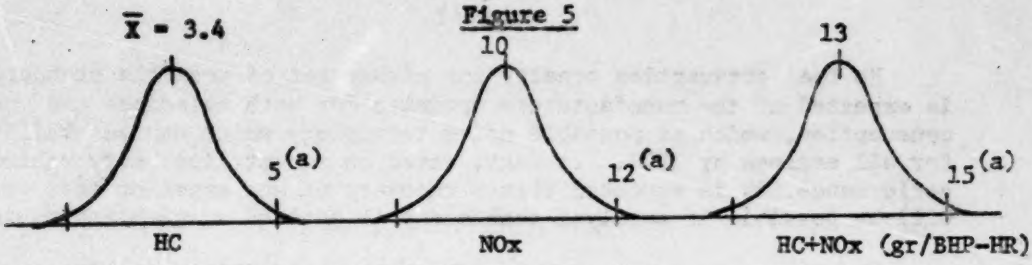
HC/CO/NOx	Diesel Engine	Gasoline Engine
3/30/9	$120	$ 75
1.5/25/9	$120	$110
1.5/15/9	$120	$165

The standards, which are now stated on a combined basis, can be expressed separately. However, for reasons discussed in Section III, a more appropriate method for the interim period is to have a separate HC standard and a combined HC + NOx standard. The more stringent individual standards presented in this technology assessment stated on the combined basis would be as follows:

separate:	HC = 1.5 gr/BHP-HR	HC = 1.5
	NOx = 9	HC + NOx =10
	CO =15	CO =15

The fact that combining the HC and NOx is not a simple addition of the two separate standards is explained by the fact that an individual standard results in actual performance distributions below the standard such that, based on past experience, manufacturers will likely have a sales weighted average HC performance of 1 gm/BHP-HR when certifying against a 1.5 gm/BHP-HR standard. In addition, there is an inverse relationship between HC and NOx emissions when using advanced control systems, such as EGR. Therefore, the probability of having high HC and NOx emissions simultaneously is very low. Data from 1974 certification engines were analyzed to demonstrate this phenomenon. Figure 5 illustrates the standards for HC and NOx which would be appropriate to the existing 15 gm/BHP-HR HC + NOx standard.

Figure 5



(a) 95% of engines certified below these levels.

Combination of HC and NOx Performance To A Combined Standards Level

Thus, in terms of current gasoline performance, HC levels of 5 and NOx levels of 12 correspond with a combined level of 15, 2 grams lower than a simple addition of the two performance levels. Standards of approximately HC = 6 and NOx = 13 would be appropriate if a 16 gram standard were stated separately.

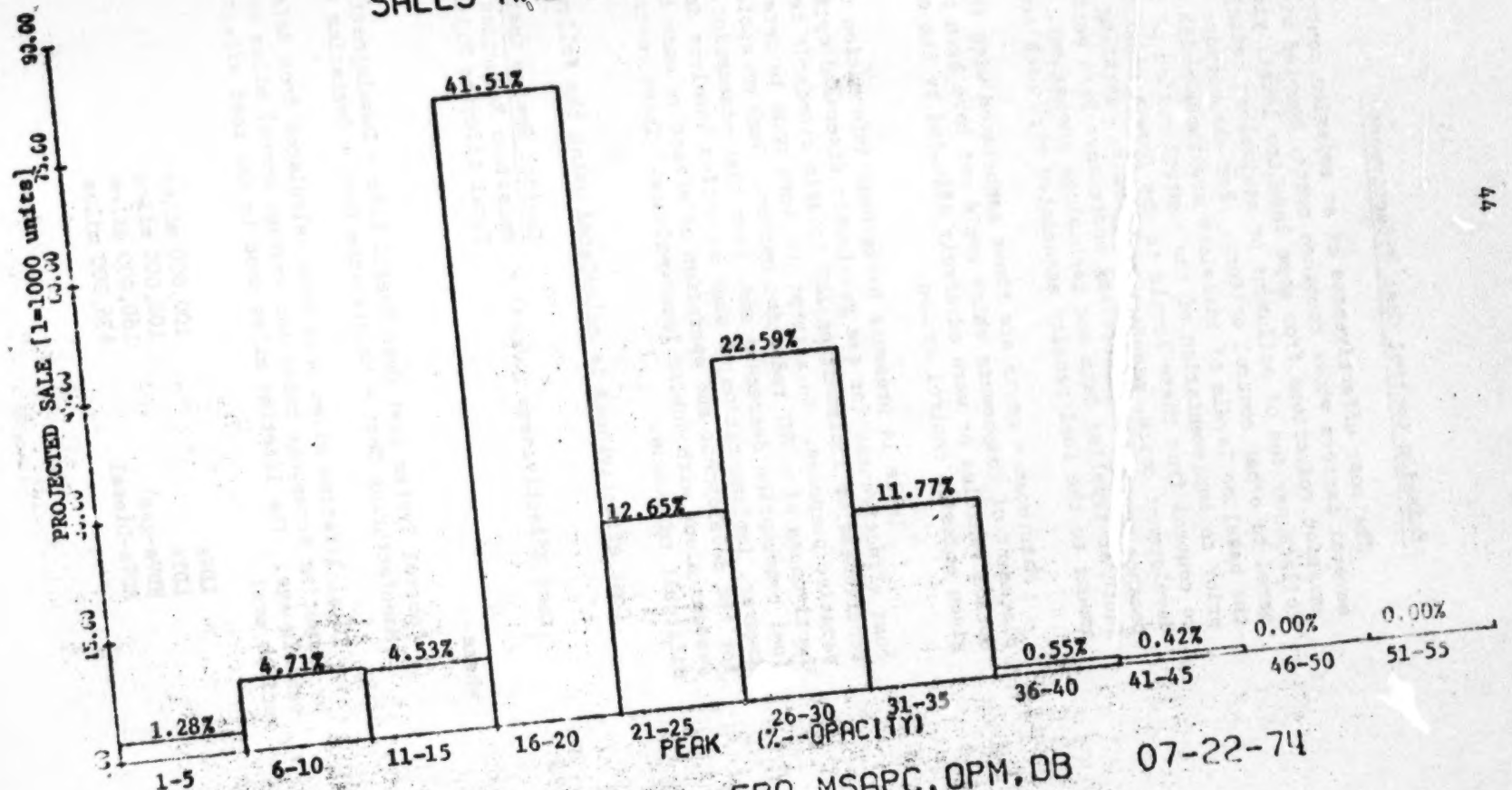
Although a reduction in smoke levels from current performance was not considered in the technology assessment and all manufacturers indicated their development work on gaseous emissions was based on no further reductions in smoke levels, there is a need to reexamine the smoke standards. This is true because current performance is well below the standards for peak smoke and it would be counter productive to allow manufacturers to degrade smoke performance in achieving reduced gaseous emission levels.

The 1974 certification peak smoke levels were analyzed and are presented in Figure 6. These data show that 99% of all Diesel engines are below 35% peak smoke opacity. Furthermore, a more recent examination of 1975 Federal and California engine certification data indicated that the ability to meet a 35% peak smoke level has been demonstrated in at least one test engine for every Diesel engine family. All Diesel engines certified in California to gaseous standards similar to those under consideration here currently meet a 35% peak value. Therefore, a change in the peak smoke standard from 50% opacity to 35% opacity should be made as protection against future degradation.

Exhaust gaseous emission standards of HC = 1.5, CO = 25, HC + NOx = 10 gm/BHP-HR are recommended for the following reasons: 1) Non-catalyst technology exists to meet these standards without a fuel penalty; 2) The intermediate CO level of 25 will allow all manufacturers to meet the standards with little or no catalyst usage. Gasoline engine first cost increase is, therefore, minimized. For Diesel engines, the total cost represents less than 0.1 cent per operating mile; 3) The lower standards represent approximately the same relative stringency as the interim LDV emission standards (80% reduction from uncontrolled), and 4) The degree of CO control lost (25 versus 15 gms/BHP-HR) is not as great as the numbers indicate because the 9 mode test over estimates urban emission reductions. Diesel engines already meet the 15 level.

Figure 6

1974 CERTIFICATION
SALES* AND DIESEL SMOKE EMISSIONS - PEAK



PREPARED BY: EPA, MSAPC, OPM, DB 07-22-74

* Projected family sales are equally split for each certification test.

V. Emission Control Cost Effectiveness

The cost effectiveness of an emission control option depends on several factors whose combined costs, coupled with an estimate of emission reductions from some baseline level, yield a statistic (in dollars per ton of pollutant or equivalent units) which can be compared to other control options. For the purpose of this analysis, the baseline levels of emissions are those which existed immediately prior to implementation of the control option of interest. The costs to control from these levels to the levels under consideration include development costs, manufacturing costs, operating costs, and maintenance costs. Manufacturing costs have been estimated from manufacturer supplied data and technology assessment. Operating costs amount to the fuel penalty associated with each control option.

Maintenance costs are those associated with the repair and replacement of components which would not have been present in pre-control option vehicles or were adversely affected by the operation of the given emission control option.

Table 14 presents background information necessary to calculate cost effectiveness for the previously discussed options. The cost effectiveness of implementing LDV interim standards is included for comparative purposes. No attempt has been made to determine the cost effectiveness of a VMT reduction option. Such an option results in large fuel consumption decreases and, from that standpoint, is attractive. However, implementation of such an option involves determining costs for the development and operation of effective mass transportation systems along with public inconvenience. These costs are extremely difficult to assess.

Cost effectiveness is calculated using the following equation:

$$\text{Cost Effectiveness (\$/ton)} = \frac{\text{Control System Cost Over Useful Life}}{\text{Emissions Reduction (tons/mile)} \times \text{Total Lifetime Miles}}$$

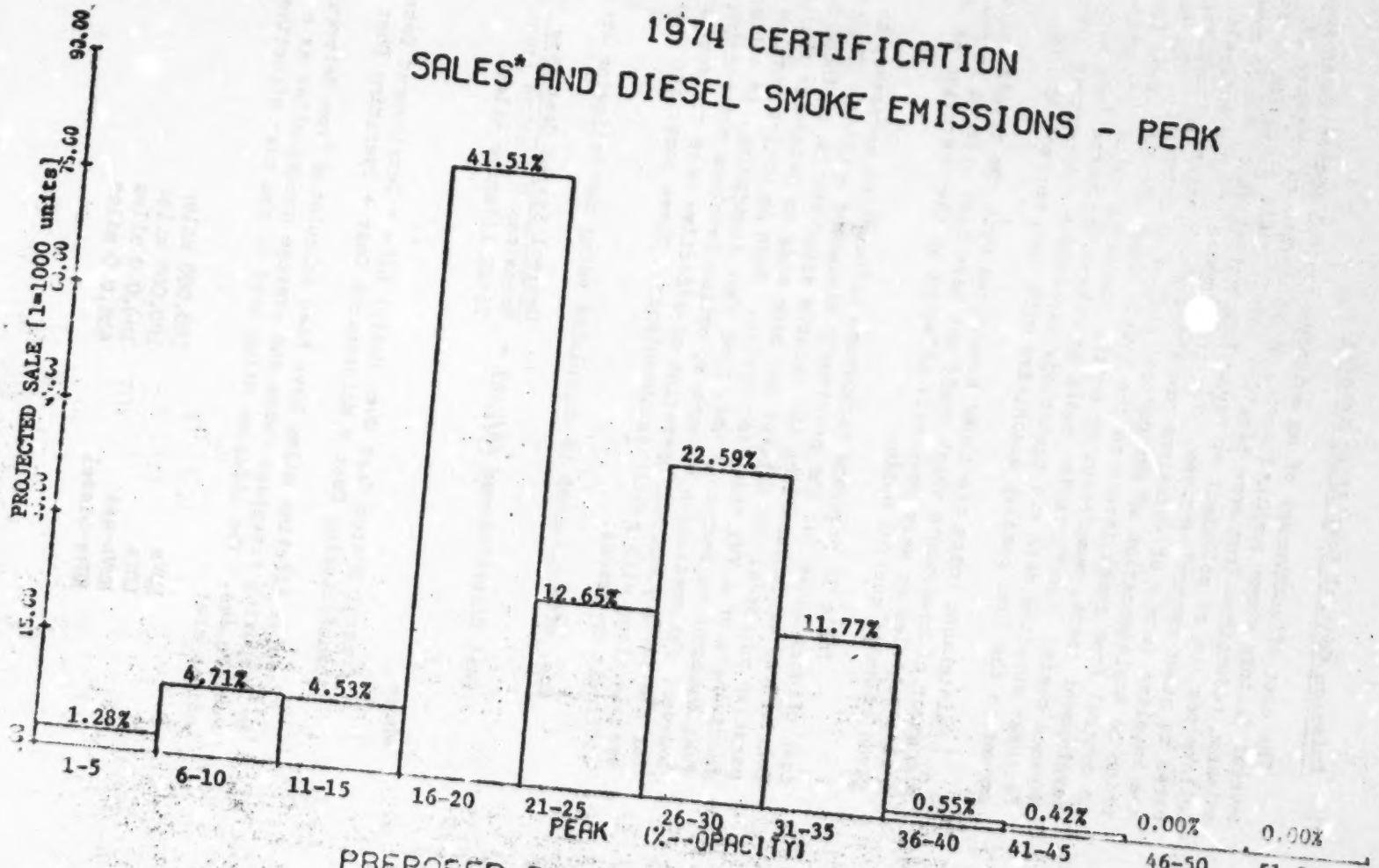
where

Control System Cost Over Useful LIfe = Development Cost + Manufacturing Cost + Maintenance Cost + Operating Cost

Total lifetime miles have been calculated from References 14 and 15 by computing scrappage rates and average annual miles as a function of vehicle age. The lifetime miles used in the cost effectiveness calculations are:

LDVs	100,000 miles
LDTs	100,000 miles
HDVs-gas	160,000 miles
HDVs-Diesel	436,000 miles

Figure 6



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LDVs	100,000 miles
LDTs	100,000 miles
HDVs-gas	160,000 miles
HDVs-Diesel	436,000 miles

Using the data presented in Table 14 as inputs to the cost effectiveness equation, Table 15 was prepared showing cost effectiveness in $/ton for each control option.

An analysis of Table 15 indicates that the initial implementation of catalyst control options on a given mobile source is extremely cost effective since such an option does not result in fuel consumption penalties from uncontrolled levels. Thus, control of LDVs, LDTs, and HDVs to interim levels which require the application of catalysts actually results in a cost davings, on an individual vehicle basis, over existing control options for these categories. In contrast, control from one catalyst option to another does not result in any cost savings. Considering just a cost effectiveness argument, LDT and HDV interim control is more cost effective than LDV control in excess of the interim levels.

Summary

Given that additional air quality reductions are needed, as is the case in many AQCRs, additional controls on HDVs and LDTs are more effective than transportation control plans for LDVs and LDTs in reducing the mobile source emission contribution, and technologically more feasible than reducing LDV standards below the statutory levels. In fact, additional HDV control is the most cost effective mobile source control option for reducing hydrocarbon emissions over current levels and is more cost effective than going from LDV interim to LDV statutory standards. Although the proposed LDT and HDV strategies will result in additional NOx and CO reduction, these reductions, based on a national vehicle mix, are of a lesser magnitude than those which are obtained by going from interim to statutory control levels for LDVs. However, implementation of LDT standards and HDV standards is more cost effective than going from LDV interim to statutory standards. Inspection/maintenance for LDVs and LDTs, while providing additional HC and CO control, is not as cost effective as stricter standards for LDTs and HDVs.

Table 14

Background Information on Cost Effectiveness for Various Control Options

Option	Base Year	Baseline Emission Levels (Expressed in Urban Equivalent Values) HC	CO	Nox	Proposed Emission Levels HC	CO	Nox	Operating Cost-Fuel Consumption Change c/	Development a/ + Manufacturing + Maintenance Cost
		grams/mile			grams/mile				
LDV/N → LDV/I	1974	3.4	39.0	3.1	1.5	15.0	2.	-13.8%	$230
		grams/mile			grams/mile				
LDV/I → LDV/S (HC, CO)	1976	1.5	15.0	2.	.41	3.4	2.	0%	$125
		grams/mile			grams/mile				
LDT/N → LDT/I	1975	3.2	33	4.2	1.7	18	2.3	0%	$ 66
		grams/mile			grams/mile				
HDV/N → HDV/I_1									
gas	1974	11.1	139	14.4	3.2	140	13.3	0%	$110
Diesel	1974	3.8	25.3	22.0	3.8	25.3	19.9	0%	$120
		grams/mile			grams/mile				
HDV/N → HDV/I_2									
gas	1974	11.1	139	14.4	6.9	146	13.3	0%	$ 75
Diesel	1974	3.8	25.3	22.0	3.8	25.3	19.9	0%	$120
		grams/mile			grams/mile				
HDV/N → HDV/I_3									
gas	1974	11.1	139	14.4	3.2	127	13.3	0% b/	$165
Diesel	1974	3.8	25.3	22.0	3.8	25.3	19.9	0%	$120
LDV, LDT/IM		15% reduction from baseline levels of HC and CO						-8%	
LDV, LDT EVAP (6gms/test)	1978	1.7	-	-	.6	-	-	0%	$ 7.30

a/ Control system costs over the useful life for each option are split among all pollutants for LDV, LDT, and HDV gas options, assigning cost to the pollutant each component is to control. For the HDV Diesel options, all costs are associated with NOx control since no additional HC or CO control is obtained.

b/ Fuel change information is based on General Motors estimates. These estimates, along with ECTD cost estimates, compiled from discussion with the HDV manufacturers.

c/ A negative change implies a decrease in fuel consumed.

I - Interim Strategy

IM - Inspection Maintenance

N - No Further Control

S - Statutory Requirement

Table 15

Cost Effectiveness of Proposed Federal Emissions Control Programs

Control Program	Baseline Emissions Program	Baseline Emissions Level 1/	Emissions After Control Program Initiated		Cost of Control ($/ton) HC	CO	NOx
LDT Interim Standard	1974 LDT Standard	2.0/20/3.1					
	HDV Current Control	5.5/58/6.3	1.7/18/2.3		202	14	53
EPA Administrators Proposed 1980-81 Fed.Standards 2/	1975 Fed. LDV Standards	1.5/15/3.1	.9/9.0/2.0		303	30	165
LDV Fed. Statutory Stds.	1975 Fed. LDV Standards	1.5/15/3.1	.41/3.4/2.0		437	41	165
HDV Fed. Interim Standard		- 3/	- 3/	Gas	20-23	0-8	136-247
				Diesel	-	-	45-119
LDV/LDT IM 4/		-	-		61-414	4-29	-
LDV/LDT EVAP		1.7	.6		50	-	-

1/ All emissions factors in grams per mile HC/CO/NOx, except for HDV.

2/ Decision of the Administrator, Application for Suspension of 1977 Motor Vehicle Exhaust Emission Standard, March 1975.

3/ Heavy Duty Vehicle (HDV) emissions levels based on 1974 vs. proposed 1979 HDV emissions standards.

1974 Standards: 16 grams/bhp-hr (HC + NOx), 40 grams/bhp-hr (CO).
1979 Proposed Standards: 1.5 grams/bhp-hr (HC), 25.0 grams/bhp-hr CO, 10.0 grams/bhp-hr (NOx).

4/ IM Cost Effectiveness calculations assume a 30% failure rate.

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